The Association for Science Education

Teaching Secondary Biology

Third Edition

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Contents

1 The principles behind secondary biology teaching

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Introduction

In this book, our aim is to help biology to be taught so that students at secondary school (we have in mind particularly the 11–16 age range) build an excellent understanding of the subject, enhance their interest in it and learn to connect ideas from disparate areas of biology. There are twelve chapters, this one and then eleven that look at particular areas within biology – such as 'cells' or 'evolution' – and discuss how each might be taught.

This book is one of a series of three Association for Science Education handbooks, the others being parallel volumes in chemistry and physics. The first edition of this book was published in 1999, over 20 years ago; the second edition in 2011, a decade ago. This third edition retains the basic structure of the previous editions but includes a number of new authors and all chapters have been substantially revised and brought up to date.

The author team has kept in mind a secondary teacher confronted with the task of teaching a specific topic, such as respiration or ecosystems, and the preparation they would need to undertake. What does such a teacher need to produce a series of effective lessons, that will also engage learners and enhance or sustain their curiosity? Some teachers will approach this task with an excellent understanding of the topic. However, we have kept in mind that not all teachers of secondary biology have a degree in the subject and that, even if they do, very few degrees cover all of secondary school biology. We hope that all teachers of secondary school biology, even if they have been teaching the subject for some time, will find much of value in here.

This chapter examines the discipline of biology and discusses approaches to teaching which enable students to engage in the discipline, to build their identity as biologists and to learn conceptual ideas in the subject.

1.1 What is biology?

It is standard for biology textbooks to assert that biology is the study of life – and this is indeed the case if we avoid a narrow interpretation that might exclude the inorganic building blocks of life, important non-living features of the environment (temperature, salinity and so on) and the fate of dead organisms (decay and/or fossilisation).

Key concepts in biology

There are a number of key concepts within biology, perhaps more than in chemistry or physics. There is no particular order that has been shown to be best for introducing these to students; indeed, many of them are specific to particular areas of biology. For example, a crucial realisation in cell and organism biology was that the cell is a fundamental unit. This insight is usually attributed to Rudolf Virchow who, in 1858, coined the epigram *Omnis cellula e cellula* ('all cells come from cells'). Virchow was a polymath; in addition to being a biologist (with some 2000 scientific publications to his name), he was also a prehistorian and a politician. He was the first to describe and name a number of diseases and other pathological conditions, including embolism, leukaemia, spina bifida and thrombosis; he introduced hair analysis into forensics and was the first to systematise how autopsies were undertaken. At the same time, he was an anti-evolutionist and called Charles Darwin an 'ignoramus', which seems a touch harsh.

Another key concept (or pair of concepts) within biology – but found in the other sciences – is to do with the flow of energy and the circulation of materials. Many students find it difficult to 'get' that while both energy (the law of conservation of energy) and matter (the law of conservation of mass) are conserved, there is a fundamental asymmetry in that energy moves in one direction, continuously dissipating, whereas matter circulates; this is true whether we are thinking at the cellular or ecosystem scale.

Other key concepts that are restricted to biology, and which will be treated in more depth in succeeding chapters, include:

- *Reproduction*. No organism is immortal and so all organisms need to give rise to individuals in future generations or become extinct.
- *Heredity*. In giving rise to the next generation, organisms may split into two (asexual reproduction) or produce specialised structures that enable either sexual or asexual reproduction. Sexual reproduction means that offspring typically differ from either of their parents. Information from one generation to another is carried in genes.

- *Evolution*. Over time, organisms change. A key insight of Charles Darwin and some other biologists, notably his contemporary Alfred Russel Wallace, was that natural selection is an inevitable consequence of the overproduction of offspring, what we now call genetics and the pressures exercised on organisms by the environment.
- *Homeostasis*. All organisms are able to regulate their internal environments to a very considerable degree – though this is more apparent in some (including homeotherms, such as most mammals and birds) than in others.

History of biology

Not all students enjoy learning large amounts of history, but small amounts can enliven the teaching of a topic (think Mendel and genetics, van Helmont and plant growth, Francis Crick, Rosalind Franklin and James Watson and the structure of DNA). More importantly, the inclusion of history can help students get a better understanding of a topic or of the nature of science. For example, thinking about why Mendel's work was under-appreciated for some 40 years can help students to realise that one really can be 'ahead of one's time' and to appreciate the way in which understanding in science (not just in biology) depends on the social and scientific context in which a discovery is made.

The story of the way in which the contributions of Francis Crick, Rosalind Franklin and James Watson to the elucidation of the structure of DNA were differentially recognised has been a feminist trope for decades. Almost every student of biology in the 14–19 age range would benefit from reading both James Watson's eminently readable, autobiographical *The Double Helix: A Personal Account of the Discovery of the Structure of DNA* (Watson, 1968) *and* Anne Sayre's feminist reclamation of Rosalind Franklin's contribution, *Rosalind Franklin and DNA* (Sayre, 1975).

The story of how van Helmont disproved the idea that plants grow by eating soil provides a simple yet effective context to learn how scientists can change scientific understanding through providing evidence to contradict current ideas. Van Helmont weighed a willow tree and some dry soil. He planted the willow tree in the soil and added water. Five years later, the willow tree had substantially gained in weight, but the weight of the dried soil was pretty much the same. He had used evidence to disprove the theory that plants gain mass by eating soil. He suggested that trees gain mass by taking in water. One hundred years later, Nicolas de Saussure provided evidence that trees gain mass from a gas in the air (that we now know is carbon dioxide).

Big ideas in biology

An influential pair of reports that link the big ideas of science to the science curriculum have been produced by Wynne Harlen and colleagues (Harlen *et al.*, 2010, 2015). In the 2010 report, Harlen and her colleagues came up with ten big ideas of science, of which four were *of* biology:

- organisms are organised on a cellular basis
- organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms
- genetic information is passed down from one generation of organisms to another
- the diversity of organisms, living and extinct, is the result of evolution

and four were *about* science – which apply to biology and to the other sciences:

- science assumes that for every effect there is one or more causes
- scientific explanations, theories and models are those that best fit the facts known at a particular time
- the knowledge produced by science is used in some technologies to create products to serve human ends
- applications of science often have ethical, social, economic and political implications.

The big ideas in the science movement started because of a wish to address what was perceived to be a fragmentation of students' learning experiences as a result of standard methods of summative assessment. Too often, it was felt, science is seen by students as requiring learning about a mass of information with many students having little appreciation of *why* they are learning what they are – or of how different topics aggregate into significant big ideas.

Each of these big ideas was then spelt out in more detail and, in the 2015 report, progression was addressed explicitly. For example, the big idea that 'organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms' was organised across the 5–17 age range as follows:

5–7

All living things need food as their source of energy as well as air, water and certain temperature conditions. Plants containing chlorophyll can use sunlight to make the food they need and can store food that they do not immediately use. Animals need food that they can break down, which comes either directly by eating plants (herbivores) or by eating animals (carnivores) which have eaten plants or other animals. Animals are ultimately dependent on plants for their survival. The relationships among organisms can be represented as food chains and food webs.

7–11

Some animals are dependent on plants in other ways as well as for food, for example for shelter and, in the case of human beings, for clothing and fuel. Plants also depend on animals in various ways. For example, many flowering plants depend on insects for pollination and on other animals for dispersing their seeds.

11–14

Interdependent organisms living together in particular environmental conditions form an ecosystem. In a stable ecosystem there are producers of food (plants), consumers (animals) and decomposers (bacteria and fungi which feed on waste products and dead organisms). The decomposers produce materials that help plants to grow, so the molecules in the organisms are constantly re-used. At the same time, energy resources pass through the ecosystem. When food is used by organisms for life processes, some energy is dissipated as heat but is replaced in the ecosystem by radiation from the Sun being used to produce plant food.

In any given ecosystem there is competition among species for the energy resources and the materials they need to live. The persistence of an ecosystem depends on the continued availability in the environment of these energy resources and materials. Plant species have adaptations to obtain the water, light, minerals and space they need to grow and reproduce in particular locations characterised by climatic, geological and hydrological conditions. If conditions change, the plant populations may change, resulting in changes to animal populations.

14–17

Human activity which controls the growth of certain plants and animals changes an ecosystem. Forestry which favours the growth of certain trees over others removes the food plants of certain animals and so reduces the diversity of species dependent on these plants and on other organisms in the food chain. Modern farming is designed to reduce biodiversity by creating conditions that are suited to particular animals and plants in order to feed the human population. The widespread use of pesticides to preserve one type of crop has widespread effects on pollinating insects on which many other plants depend. Human activity of this kind creates a simple and unnatural ecosystem which limits biodiversity and results in the loss of culturally valuable landscape and wildlife.

(Harlen et al., 2015: 27)

The Harlen reports have had considerable impact in the UK and in a number of other countries. In England, Northern Ireland and Wales, it is hoped that work by the Royal Society of Biology, along with the equivalent professional organisations for chemistry and physics, will mean that the next version of the science National Curriculum is informed by them. For science teachers, one of the benefits of the Harlen reports is that they can facilitate departmental curriculum planning, helping to ensure that there is coherence in student experiences. As can be seen from the above, the Harlen progression goes to post-16, and good 11–16 teaching should prepare the groundwork for post-16 biology.

1.2 Doing biology

Scientists are always asking *why* things happen or *how* things happen. By asking questions like this, they may be able to come up with new theories to explain new findings, and then test those theories. Scientific ideas can never be said to be proven: every idea is potentially falsifiable if data eventually contradict it. But learning how to ask 'how' and 'why' is fundamental to educating new biologists. Such biologists may go on to an extraordinarily wide range of careers, many with people (particularly in the medical professions), some out-of-doors, and some in laboratories or other specialised sites such as zoos. Biologists are employed in an enormous number of different jobs and at every level, whether a student leaves school at the first opportunity or goes on to take a master's degree or even a doctorate in the subject.

Practical biology

Biology is a practical subject, as much as any other science. It is therefore a matter of deep regret if students sometimes experience substantially less practical work in biology than in other sciences, instead too often spending long periods of time making notes on the structure and function of organs or specialised cells.

At the same time, there are a number of distinctive characteristics about biology that mean that practical work in biology differs from practical work in chemistry or in physics. For a start, many organisms are sentient, that is, capable of experiencing pleasure and of suffering (experiencing pain). This means that they cannot be used for certain experiments, whatever the educational benefits might be. Indeed, there is a move to be respectful to all living organisms even if, as in the case, for instance, of unicellular organisms, it seems certain that they are incapable of suffering.

Then there is the fact that organisms, even within a species or local population, are rarely identical. At school level, a chemistry teacher does not have to worry about the possibility that different samples of copper will have different thermal conductivities; biologists cannot make comparable assumptions about their objects of study.

Related to this is the issue that it can be difficult in biology to control variables in a way that physical scientists would expect. Often, with care, this can be done, even when there are multiple variables, using appropriate data collection design to remove any systematic bias. Even if it is difficult to control variables, their effect can also be accounted for in analysis through use of appropriate statistics. Nevertheless, biology does sometimes require more interpretation of data than in other sciences. Furthermore, there are times when biology can, with hindsight, be seen to have been more subjective. There is a long history of white, male biologists gathering data that 'showed' that women and people of other ethnicities were less intelligent than they (Gould, 1981). Much of this bias was probably unconscious – but bias it was.

Finally, although all the sciences can profitably be studied out of doors (Braund and Reiss, 2004), it is especially important that such study be undertaken in biology. Although much ecology can valuably be undertaken in the laboratory, the subject comes alive when studied out of doors, whether in school grounds or further afield. It is a matter of deep regret that fieldwork is increasingly threatened in school biology in the UK (Tilling, 2018).

Mathematics in biology

Mathematics is important in all the sciences but the various sciences are not the same in the use that they make of mathematics (Boohan, 2010). At secondary school level, even up to age 19, there is no need, for example, for calculus in biology, whereas chemistry and physics are helped if simple differential equations can at least be introduced (for example, when studying rates of reactions and changes of momentum).

However, it is not the case that school biology always requires simpler mathematics than do the other sciences. As outlined above, biology has an especial need for statistics. Nowadays, calculators and online software can take much of the drudgery out of statistics. Furthermore, there are many excellent introductions to mathematics for biologists – though these are hardly needed pre-16. Nevertheless, what is valuable is for students to have an understanding as to *why* they are taking the measurements and using the statistical tests that they are.

Biological reasoning

Much of science is about reasoning: formulating hypotheses, making deductions, developing an argument and being able both to buttress it and to critique it. In biology, there is an especial need for students to develop the capacity to appreciate the importance of probability. Of course, probability plays an important role in other sciences (such as when a particular radioactive atom decays) but in biology probabilistic reasoning is important in many areas (mutations, independent assortment, whether a predator catches prey in a particular hunt, whether a tree is killed by lightning or not, whether succession takes one direction or another, and so on). One of the difficult things we want students to appreciate is when we can be pretty sure about what will happen next in biology as opposed to when there are a number of possibilities.

Biology is also noticeable (though it shares this feature with parts of earth sciences and cosmology) in the importance of historical reasoning. To get a good understanding of the history of life over the last three and a half thousand million years or so requires the ability to imagine and then to reason historically.

Biology in context

Some students love 'pure' biology but most are fascinated by biology in context. The student who may have little interest in the semi-permeability of membranes may become captivated by the realisation that the various problems that result from having cystic fibrosis can all be traced back to damage to certain proteins that carry ions across such membranes.

As a science, biology is fortunate in that so much of it can be taught in context. Perhaps two contexts stand out: health and the environment. There was a time when biology teaching about health for 11–16-year-old students consisted of little more than diatribes against cigarette smoking and the use of illicit drugs along with a litany of things that could go wrong with various parts of the body (everything from vitamin deficiencies to cheerful lists of sexually transmitted infections). *Plus ça change* – and yet the difference now is that there is far more of a link from molecular biology through cell biology to whole organism biology, as in the cystic fibrosis example above.

Teaching about the environment has changed too over the years. No longer are contexts dominated by oil spills, the grubbing out of hedgerows, acid rain and the hole in the ozone layer. Nowadays, two anthropogenic instances of environmental damage stand out: climate change (including global warming, more extreme weather events, ocean acidification and rising sea levels) and the ever-accelerating loss of biodiversity.

Ethics in biology

Every science needs to take account of ethical implications (Jones *et al*., 2010), but no science more so than biology. Indeed, almost every biology topic seems to throw up ethical issues. Should we change the genes of individuals to prevent genetic diseases? Is it right to exterminate certain species, such as the *Anopheles* mosquitoes that transmit malaria? At what stage during development does an embryo become a person or does this happen at fertilisation? How much money should we spend conserving a species so that it does not go extinct? Should badgers be culled to prevent the spread of bovine tuberculosis? And so on.

Too often, biology courses simply raise such ethical questions. While this is useful, it can overwhelm students. To help them move forward, they may benefit from being taught one or more ethical frameworks within which to consider such ethical questions (for example, Levinson and Reiss, 2003).

1.3 Learning biology

When learning biology, students should not only learn conceptual ideas, but also get a good understanding of what biology is and how it is done. By designing teaching and learning approaches which enable students to learn, and which enable learners to experience 'doing' biology, we should give students the chance to develop the feeling that biology 'is for me' and is also of broader value to society. This means that teaching and learning requires individuals to think.

Constructing understanding

Building learning by requiring students to think ideas into existence complies with constructivist ideas about learning. The theory of social constructivism says that such building of ideas happens better in social interaction with others, such as a teacher or a student's peers. Such interaction scaffolds students' developing understanding. The way in which learning activities are designed by a teacher enables such scaffolding to take place. Hence, teachers have to consider a learner's starting point, and how best to enable (or scaffold) them to build up ideas. Engaging in biological reasoning provides an excellent framework, where students make deductions from observational and experimental evidence that they can share and hone with others.

Thinking together through a rich diet of talk is essential for developing successful learners and building biological reasoning skills. When educational dialogue is working well, students listen to each other, they share their ideas, they justify their ideas and engage with each other's views. The teacher's role in this is important, and includes inviting students to build on each other's ideas ('Do you agree?', 'Can you add?'), challenging ideas ('Are you sure?), inviting reasoning ('Why?', 'How?'), co-ordinating ideas ('So we all think that …'), connecting ('Last lesson …'), inviting reflection ('What have you learned?'), guiding the dialogue or activity ('Have you thought about …?'), and inviting original ideas ('What do you think about …?').

Conceptual change

Rich dialogue can also help students to engage with their own prior knowledge, drawing on different funds of knowledge across increasingly diverse classrooms. Indeed, some of learners' prior ideas can be very different to scientifically accepted knowledge. These ideas can be labelled misconceptions or, perhaps better, alternative conceptions, as many such ideas are simply learners' attempts to make sense of their world using 'common sense' rather than scientific logic (Driver, 2014). It is difficult for students to give up their alternative conceptions, so lessons and learning activities need careful design. Teachers need to know the alternative conceptions their students hold, and students need opportunities to make their ideas explicit, to encounter alternative ideas, and to assimilate such ideas into their thinking.

Diagnostic tasks are useful tools to help teachers uncover alternative conceptions, some examples of which are listed below:

- Multiple choice questions, if well-designed, may have options which include the scientific view, alongside common alternative conceptions.
- Sometimes a student's understanding may be more nuanced, and asking them to express how confident they feel about each answer may give the teacher a better insight into their understanding, and a better starting point for addressing their difficulties.
- Asking students to identify whether statements are correct, partially correct or incorrect, justifying their ideas with reasons, can help explore the cause of students' difficulties, as can more open-ended questions.
- Refutation tasks are also useful, asking students to explain why a particular alternative conception is wrong.

Making students realise that their ideas may be naive, by generating conflict in their mind between their own ideas and evidence, is one approach to changing their ideas. For example, a teacher may ask students to make a prediction before a piece of practical work. Their prediction is based on their prior ideas, and makes those ideas explicit to the teacher, but also to the students themselves, because the data they collect may conflict with those ideas. You can do the same with simulations: ask students to make predictions, run the simulation, and generate that kind of conflict in their minds. Concept cartoons can help achieve the same aims, but through dialogue (Keogh and Naylor, 2000). A concept cartoon provides a picture of a scientific phenomenon, with different people giving alternative explanations of that phenomenon. Inviting students to say what they think or to decide how much they agree with various statements, and then justify their position to each other, creates dialogue that can help students to unpick their current understanding.

However, such cognitive conflict is not the only way to think about conceptual change. An 'evolutionary change' model views conceptual change as being a more gradual and ongoing process, where students' prior conceptions are used as resources for learning, regardless of whether these prior conceptions are scientifically accurate notions or misconceptions. You can think of this as the step-by-step development of understanding, building pieces of knowledge upon existing understanding. Whichever model a teacher exploits (and many would adopt both, depending on the circumstances), the teacher has to structure ideas in sequence, ensuring good progression, with ideas building on each other over time, and making connections to other curriculum areas, both within biology, within science, and in other subjects.

Problems with language

Language is one of our main tools to help students learn biology. But it can also be our biggest obstacle. This is not just because of unfamiliar complex scientific words (like homeostasis or nephron), but because some words often have different meanings in biology. For example, many people would talk about artificial respiration when referring to the 'kiss of life', but respiration in a biological sense is the chemical process which releases energy from glucose (or other substrates) and occurs in cells. Even common, everyday words like random or abundance may have very particular meanings in biology. Because we are biologists, it can be very easy to use such complex vocabulary without even thinking about it. As a result, we need to focus on clear, logical explanations, rather than defaulting to specialist language. For example, talking about 'more stomata on the lower epidermis' makes no sense unless you have explained stomata and their role, have spent time getting students to examine the structure of a leaf, and have discussed with them how all these relate to the processes of transpiration and evaporation.

Even then, some of the grammatical conventions we use in biology can be a challenge. Logical connectives are essential to constructing a logical scientific argument because they help make links between claims and data, and because they can be used when making comparisons and when highlighting differences. These are words which suggest cause (for example, because), addition (for example, and), time (for example, after/before) and opposition (for example, otherwise). However, students can find their use difficult.

Finally, science does not just communicate through words, but through diagrams, physical models, graphs, symbols, mathematics and equations. Some of these may make ideas easier to understand (imagine trying to learn the cross-sectional structure of a leaf through reading about it without a diagram). But others, such as mathematics, may present obstacles to students' understanding.

Helping students with language

Because language can be a challenge, it is important to plan for talk, reading and writing.

Talk

We wrote above about encouraging dialogue, but that can happen as a whole class, in small groups, or in pairs. Groups tend to work better when each student has a particular role, and there are various grouping strategies which can encourage talk in different ways. For example, jigsaw (students team up in expert groups and then split apart into new groups, with one member from each expert group), snowball (pairs discuss an idea, then team up into groups of four, then into groups of eight, etc.), envoys (a group discusses an idea and then sends an envoy to explain their ideas to a different group), and spokespeople (one person summarises a group's discussion) are easy-to-implement ways to encourage talk.

Reading

Reading is important; so much so that students should be able to read, re-read and reflect upon text, building connections with prior knowledge. Constructing and deconstructing text to help understand it can help in this process, and may include strategies like:

- completing text, tables or diagrams (for example, completing missing words, completing missing labels on diagrams or completing a compare-and-contrast table)
- sequencing and labelling (for example, labelling the digestive system, or ordering key phrases which describe the process of natural selection)
- matching (for example, matching key words to definitions)
- predicting (for example, predicting the final words of a sentence, or the question, given an answer)

- labelling and highlighting (for example, highlighting words which relate to a particular organ system in a piece of text)
- processing a piece of text (for example, using information given in a text; answering questions about a text; converting a piece of text to a flow chart).

Writing

Writing has a number of functions in biology teaching and learning. Writing is first and foremost a tool to help prompt students to think and to learn. Writing helps students to formulate their ideas (for example, creating a graphic organiser or preparing a summary of the key points). Writing helps students to engage in biological reasoning (for example, writing up a practical inquiry, setting out methods, prediction, findings and conclusion). Writing helps students to communicate their understanding, not just in conventional ways, but in more creative ways, such as stories, newspaper articles or blogs.

Allowing students to engage with language, and to use language to help develop and communicate their skills and understanding, is a challenge, but essential to effective learning of biology.

Practical work and inquiry

Practical work is part of what biologists do, and engaging with it (including fieldwork) gives students a sense of what it means to be a biologist. It can also help students to learn. It may help students to develop:

- essential practical skills (for example, using a measuring cylinder or a micropipette)
- their observation abilities (for example, in dissection or drawing activities)
- problem-solving skills (for example, working out which urine sample is from a diabetic)
- classification skills, by recognising that groups of organisms share similar structures
- conceptual ideas through investigation (for example, using bicarbonate indicator to investigate the effect of light intensity on photosynthetic rate).

Practical work may also be used by a teacher as a demonstration to support an explanation (such as the way valves work in the heart) or simply to illustrate a phenomenon (for example, testing a leaf for starch).

When you use a piece of practical work as part of a learning activity, make sure you understand the purpose. Think to yourself, 'What are you asking students to do or see?', 'Will they do/see it?', 'What will they learn *how* to do?' and 'What conceptual learning will take place?' (Reiss and Abrahams, 2016). If you don't think about these questions, you won't consider how to draw learning from the practical. For example, a student can test a leaf for starch, but unless you ask the right questions, they won't learn anything from what they observe, and may get lost in the complexity of what they are doing, rather than spending time thinking about and understanding their results.

If the practical work you choose involves investigation, then your students may be doing inquiry. In biology, good inquiry is sometimes hard to fit into an hour lesson block, and so teachers often default to more illustrative practical tasks. Biological inquiry may involve extended project work, data collection over time, and inferences from observation, rather than just from experimentation. Inquiry does not have to involve practical investigation, but may feature any of the following components:

- ➜ a question to investigate
- ➜ collection of evidence
- ➜ analysis of evidence
- ➜ explaining the evidence
- ➜ connecting their explanation to existing scientific knowledge
- ➜ communicating and justifying their explanation
- ➜ reflecting upon and evaluating their inquiry.

Teachers can choose whether students need to undertake an inquiry which involves all of these skills, or whether they could simply provide data to be analysed, or an experimental protocol and findings which students then reflect upon and evaluate. Often, teachers provide a mixture of inquiry types over the years of secondary education so that students experience open, closed and guided inquiry work. Some inquiries may fit alongside physical science inquiries quite well (for example, osmosis and enzymes), while others require a different approach (such as estimating the diversity index in a meadow or designing a 75 g 'healthy' snack bar).

Learning in context

The inquiry approaches above can be particularly effective when asking students to learn biology through consideration of biological contexts. As biology teachers, we are fortunate. Our students feel a connection to biology because they themselves are living things, living in their own habitat and ecosystem. Because of this, when students learn about biology through contexts, they are often more motivated, and their interest in biology lessons increases. Contexts also help students perceive relations between science and everyday life, enhancing the relevance of biology lessons. Contexts are often introduced through the use of media, including newspapers and magazines. Topics which are conducive to a context-led approach include health, agriculture, genetics, global warming, sustainability, disease, habitat destruction and drug abuse. However, it is possible to use contexts across the curriculum to foster students' motivation and their perception of the relevance of biology to everyday life. This is important because biology teaching should foster students' sense that biology 'is for them', and creating a motivating and relevant classroom is important.

Using digital technologies

Inquiry can also be made easier by the use of digital technologies. Being able to observe changes in variables in biological contexts can take time (for example, growth of bamboo over a week) and can involve lots of laborious data collection. Data logging offers a solution, by automating data collection and offering more accurate data collection, allowing time in lessons to undertake analysis, interpretation of results, formation of conclusions and general critique. Data-logging sensors can measure changes in atmospheric oxygen, light, humidity, temperature and carbon dioxide, and can investigate biological processes as broad as respiration, pollution, osmosis, transpiration, photosynthesis, homeostasis and circulation.

Mobile phones can be useful as there are numerous apps for supporting identification of organisms, etc. Mobile phones can also be used to record data such as the growth of bacterial colonies on a Petri dish or by taking photographs or videos down a microscope. Small attachments can be purchased that enable mobile phones to function as microscopes.

Given the microscopic and sub-microscopic nature of biological processes (such as membrane transport), animations are essential to help students visualise such processes, as are simulations, which allow students to undertake inquiry on such processes by altering independent variables and observing the impact on dependent variables. The use of collaborative technologies, such as WhatsApp, wikis and blogs, can help students to work together remotely on extended project tasks.

1.4 Final thoughts

What you have read above sets out a vision for learning biology. Learning biology is not about learning the contents of a textbook. Learning biology is about conceptual learning, learning about what it means to do biology and learning what it means to be a biologist. We hope that this book helps you to achieve these aims.

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2 Cells

Chris Harrison and Rachel Waterhouse

Topic overview

Cell biology is the study of cell structure and function, and it revolves around the concept that the cell is the fundamental unit of life. Focusing on the cell permits a foundational understanding of the processes that tissues, organs and organ systems are involved in.

While most students have a concept of what 'living' means, they often find it difficult to articulate and tend to define living in terms of what they believe a living organism similar to themselves is capable of: mainly movement, growth or needing food. Life can be thought of as the result of the various interactions between the many different chemical substances that make up a cell and the processes that allow an organism to function.

2.1 Cell biology

Cell theory is one of the basic principles of biology. Cell theory states: all living organisms are composed of cells and all life comes from pre-existing cells. Organisms may be unicellular or multicellular. Credit for the formulation of this theory is given to the German scientists Theodor Schwann, Matthias Schleiden and Rudolf Virchow. The term 'cell' today describes a microscopic unit of life that separates itself from its surroundings by a thin partition, the cell membrane.

The two primary kinds of cells are eukaryotic cells, which have a true nucleus containing DNA (deoxyribonucleic acid) surrounded by a nuclear membrane, and prokaryotic cells, in which the DNA is coiled up in a region called the nucleoid. DNA is also present in smaller pieces of nucleic acids called plasmids spread through the cytoplasm. The DNA and RNA (ribonucleic acid) carry the genetic information necessary for directing cellular activities, mainly through the control of protein synthesis in the cytoplasm. Cells contain organelles (literally 'little organs') that carry out specific functions necessary for normal cellular operation. One of the largest organelles in the cell is the mitochondrion. Mitochondria contain enzymes that drive the reactions of respiration (see Chapter 3). Most organelles have a surrounding membrane but some, like ribosomes (the site of protein synthesis), do not. The organelles are situated in a jelly-like substance called cytoplasm and surrounded by the cell membrane.

This chapter begins with a discussion of some of the characteristics of life that are displayed by whole organisms and how these processes relate back to cells and the many chemical reactions that occur within them. We then provide guidance on using microscopes to view cells and tissues. The remainder of the chapter is mainly concerned with life processes at the molecular and cellular level. An understanding of this from a cell biology perspective underpins the study of the many other aspects of biological science that are addressed in other chapters (Chapters 3–7).

Prior knowledge and experience

Some students will know that living things are made up of cells but they are unlikely to have studied this topic in any depth. Research has shown that younger students sometimes think the words 'molecule' and 'cell' have the same meaning and this can give rise to a generalised concept of living things being made up of 'very small units' that can be molecules or cells. In addition, students sometimes think that many of the non-cellular things studied in the context of biology lessons (such as proteins, carbohydrates and water) are actually made of cells.

A teaching sequence

The activities described in the first three sections are aimed mainly at students aged 11–14 years old. The suggested approach is intended to help students gain an overview of what biology is about through encouraging them to observe carefully and note similarities and differences. The Characteristics of Living Organisms (COLO) outlines some of the processes that are recognisable in living things and also highlights the differences between living and non-living things. To maintain links between ideas, teachers might consider 'How small can a living thing be?' and use practical microscope activities to achieve this. Cell theory is a key idea in biology and realising that what happens at cellular level has implications for organisms is important. The final part of the teaching sequence picks up on ideas of what is happening at molecular level in cells and how these processes support life in organisms; this work is more suitable for 14–16-year-old students. This includes an introduction to enzymes and the processes of gas exchange, respiration and excretion, which are dealt with in more detail in Chapters 3 and 4.

2.2 Characteristics of living organisms (COLO)

Most children's concept of living is in relation to themselves. They 'know' that they are alive and so if something 'does' things similar to them, then it must be living too. Pets, garden birds, worms, insects and spiders all move and feed and grow and so are recognised and categorised as living. However, because almost all plants and some animals, such as barnacles, coral and limpets, seem to stay in one place, children are less sure whether to class these as living. Young children often believe that the wind is living because it moves, and fire is alive because it consumes material; while such ideas might be considered naive, stories and mythology they have encountered at home sometimes support these ideas. The standard way in which COLO is introduced is using the acronym MRS GREN (M = movement, R = respiration, S = sensitivity, G = growth, R = reproduction, E = excretion, N = nutrition). While this approach does help many students to remember the names of the seven characteristics, it does not necessarily help them understand the processes that go on in living organisms.

KEY ACTIVITIES

Observing living organisms

It helps to give students an opportunity to observe a range of living organisms in settings which are as natural as possible. These might be:

1. setting up a large tank with a layer of woodland soil or garden soil and/or a pile of fallen leaves for students to search for any insects, worms, spiders, woodlice, snails, slugs, mites, etc.
2. pond dipping or stream dipping
3. a field trip to an unkempt patch of land, a rotting log in the school grounds, a local park or a wood.

With each of these activities, students can observe what the animals and plants are doing, possibly using a magnifying glass or capturing the animals from each habitat using pooters, nets, plastic spoons, etc., and observing their living organisms back in the classroom with a binocular microscope. While the students are likely to observe animals moving or feeding or possibly reproducing (either directly or by finding eggs), they will also gain some ideas of how these organisms respond to light, moisture or other organisms. Their observation of plants may illustrate seeds, fruits and possibly reproductive structures of mosses, and they may find plant leaves with holes where animals have fed on them.

While you will be able to find video clips of living organisms, it is advisable to do 'live' observations, as these help students in developing their observational skills and in building a respect for working with living organisms. The time needed for careful observation is rarely scheduled into video footage, plus being so close to the organisms and realising they can interact with you is a different experience to seeing them on a screen. In each case, try to return the animals to their original site and move logs, stones and leaves gently back into position.

The aim of this type of activity is for students to develop their observational skills and relate their findings to COLO, rather than getting preoccupied with identification or classification. However, it does help if you know the difference between a slug and a snail, and an insect and a woodlouse. The Field Studies Council do free 'bug hunting' sheets and sell some reasonably priced identification guides for different habitats.

Tip

A good resource to be used both for diagnostic assessment and to support learning in this area has been produced by the Best Evidence Science Teaching project (BEST) at the University of York, whose website address is given at the end of this chapter.

It is worth making clear to students that animals that do not move from place to place, including many marine organisms such as adult coral, barnacles and mussels, live in an environment that is moving; their food comes to them and they filter it out of the water around them.

Students could compare the characteristics of living organisms with some non-living things that 'do' things that might initially suggest that they are living: for example, battery-powered toys or robots that move and appear to be responsive. The observable key 'living' processes that they do not display are reproduction, respiration and growth.

Science in context

Many living processes can be discussed in connection with life cycles. Animals such as stick insects are easily maintained in school laboratories, and students can study their growth and development from the egg to the adult stage. This could include a consideration of their food preferences and patterns of movement.

Plants that complete their life cycle in a relatively short space of time can also be studied. For example, pea or bean seeds planted in early spring will become mature and produce seeds before the end of the summer term. White

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