Biology

A conversation with Helen Slipper

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What do Year 9 students know, understand and can do, if you have taught them a rich, challenging biology curriculum?

When you consider the different strands of biology, you can make connections between them, but some of them stand alone as well, such as plant biology, human biology, and environmental studies. But I would want a Year 9 student to possess a solid foundation of scientific knowledge, the factual side of science that just opens their eyes to the world around them. You also need the disciplinary knowledge of science. We often talk about science experiments, investigations that find something out. It is those thought processes that come together where students are applying this reasoning in their everyday lives, but do not always realise it. It is the same process you go through when the TV remote control is not working. To make it work, you give it a bit of a slap on your hand and try again. Essentially, you have changed one variable and tested it to see if it works. And then, if that does not work, you take a battery out, put another one in, and you try it again. What you do each time is actually the same process as what you would do in a science laboratory – you change the variable, run the test and note the results.

Our mantra is, 'Knowing stuff makes a difference.' Where we really focused on using retrieval practice strategies at the beginning of lessons, it has been transformative in science. When we have looked at what we want students to know, we have made sure there are some really core things we want them to know. When we want them to know something specific, such as the word equation for photosynthesis, we make sure they know that verbatim, because, if not, they cannot apply it, and that has built their confidence. And then they feel as though they can tackle some of those more challenging aspects of the discipline.

We work hard on making the abstract concrete. How do we get them to see something that is invisible? We do a lot of work on cells, and that is a key core concept in biology – numerous different types of cells, different contexts that they then arise in, and how they have an effect on the organism. Earlier this year, I taught them what a palisade cell was. I taught them that this is a cell within a leaf and we were then moving on to photosynthesis and leaf structure. I thought I cannot really put all this together unless they have got some appreciation of what we are talking about at the moment. I took the class outside to look at some leaves on plants. And I said, 'I want you to be really observant: not just, it is green, it is round but textures and shapes. Is it all one part? Is it made of multi-parts? What can you actually see on a macroscale?' And when we then gathered back together and discussed it, they cited things like, 'Well the top was leathery or waxy.' And then they said, 'Well it had lines in it; it looked like veins' (veins were something that they already knew). So, they were able to piece some knowledge together. We were able to talk about the cuticle, the waterproof layer on the top of the leaf, and how it prevents water from evaporating. Suddenly, they had the context in real life: 'I saw that waxy layer' or, 'I saw those veins; now I understand that they connect into the stem, and they go right down to the roots. And this is how water is transported through the plant.' It brought it to life for them, rather than the 2D diagram that we stick on the board, and say this layer is this, this layer is that. It really made a big difference.

Where do you begin the science curriculum in Year 7 at Bottisham Village College?

Science does have some benefits, compared with some of the other national curriculum subjects, in that it is very clear what needs to be taught. You look at art, by contrast, and it is incredibly vague, which actually has lots of potential, as long as you are pretty clear about making the most of those opportunities. So, we began planning with the national programmes of study. Alongside that, we had the key stage 2 programme to answer the question, ‘What do we expect students to have learned by the time they come to us?’ Then we researched our partner primary school websites, and asked, ‘Where is their curriculum intent?’, ‘Where is their curriculum structure?’. We compared them and identified similarities and differences. It was fascinating to see that one primary school was teaching science thematically. So, when they were teaching forces, it was all in the context of trebuchets (a huge, long-armed catapult that launched projectiles), because they had a Roman theme in school, so they had linked it to history and other curriculum strands. Whereas another school was delivering science in explicitly scientific units, such as ‘electricity’, ‘food chains’, and ‘energy’.

Whilst the primaries delivered science in different ways, we found that the core content they covered was consistent because they were following the national curriculum programmes of study. But their weakest area was working scientifically, the scientific application of skills. The disciplinary knowledge was not as easy to deliver, because they do not have the specialist equipment that we have in a secondary school. So, we moved from there, to then look at the key stage 3 programme of study and where the connections and the links were with what had been delivered at key stage 2, and then we considered key stage 4 to establish where key stage 3 maintains coherence with key stage 4. That was one of our most interesting areas because these are our two key stages of expertise.

There is a huge overlap between what is specified in the key stage 3 programme and what is in a GCSE specification. This gave us scope to establish curriculum threads throughout the five years of secondary science education. To communicate that sense of a continuous thread throughout the five years, we constructed our curriculum with the same topic title threads throughout. It means that when we get to Year 7, we say to the students, we are studying a topic about ‘homeostasis and response'. We explain that homeostasis means the constant internal environment and body regulation, including temperature, hormones, etc., so that when they then come back to it in Year 10, and we begin a topic called 'homeostasis and response', they say, 'Oh, I have done this topic before', and we make better connections with them, straight away.

Biology was particularly interesting. We felt we had quite a few threads to follow, so when you took the ecology topic, it was very difficult to say, well we can take the ecology topic, how does that link to the reproduction topic? And how does that link to the nervous system? Well, actually, they are quite isolated when we are going through key stage 3 and GCSE. We want to keep those separate strands, so they are going to be built upon each year. We have worked hard on constructing a spiral curriculum across the five years so that we revisit topics regularly. We have found that it has made a big difference to students' recall because we point out they have learned this topic last year and now we will build upon what they learned.

We have identified some topics, for example, our ecology topic, where we do not get the opportunity to revisit each year. That has been more unique to biology, where there have been more discrete topics. We are now trying to establish the order in which to put those topics, to make sure that we can still make cross-topic links – that there is still spaced practice, recall and retrieval – to make sure it still stays fresh when we get to it later. We do not want to re-teach what we taught in key stage 3, we want to recall it and move on.

In contrast, it is quite different in chemistry and physics; the latter has energy running through pretty much every single year, along with forces and waves, they could come back to, year on year. The chemists have a different design because there are quite a number of things students need to know early on before they can access other topic areas. If you do not know what atoms are and what chemical reactions are, you would not be able to go on to study rates of reaction. You could not go on to study organic chemistry and the interactions of those different types of compounds, because you need the foundations first. So, it was quite interesting that chemistry started to branch later into other areas, whereas biology started some basics, and then it branches off and fragments much earlier on. This illustrates the unique shape, character, and DNA of the individual science subjects; they do not fall into nice neat boxes.

So, those are the principles behind our curriculum decision-making. When we began constructing our curriculum, the biologists wanted to begin with cells, the physicists with energy and the chemists with particle theory! If we begin with cells, you overwhelm the Year 7s with a massive amount of tier three vocabulary about something microscopic and difficult to put into context. So, we begin Year 7 with a couple of physics topics on energy and one on the particle model, building on their knowledge from key stage 2 where they will have learned about solids, liquids, gases, and particles. That said, we did not want to feel like we were teaching one subject at a time, without each subject weaving between the other two, to make those links. So, we do bring in the biology cell topic at the start to make the connection with energy.

We have taught the units on rotation this year, due to equipment constraints, but we also wanted to see whether it was easier to teach energy, because we had taught cell biology first and vice-versa. So, some groups start with cell biology and others with energy. The trouble is, some units should probably be taught simultaneously. We will review and tweak the curriculum, depending upon how students' learning progresses.

We are a growing school which is soon expanding up to a ten-form entry. This expansion has broadened our student demographic and we have a whole class of lower prior attaining students who need an alternative curriculum. We have identified the most basic curriculum building blocks in science. Then we have identified the next ones. We then identified what we can provide to stretch and challenge those students who are secure with their key stage 2 science and are ready to absolutely fly. We want a key stage 3 curriculum which will move into their GCSE and onto A level and beyond. We have introduced a system of age-related expectations. Students fall into three broad bands of 'developing, secure and exceeding'. From a science perspective, 'Knowing stuff makes a difference'. Students cannot understand until they know certain pieces of information.

So, for those students joining the school, we use baseline checks. We use a variety of resources and questions at the beginning of a topic, to see what they already know. We use Salters diagnostic materials which allow us to ask a question that might expose a common misconception.

Once we have a firm grasp of what the students know and understand, we decide where to begin a topic. Our first question is: 'Do they know the foundational information for this topic?' If they do, we check that they can understand it. This approach strengthens students' starting points and ensures curriculum continuity between primary and secondary. It was prompted by our line manager asking a simple question: 'In curriculum terms, how do you know where to begin teaching science to Year 7?' We want our 'transition model' to strengthen curriculum coherence between our partner primaries and the secondary school.

The recent increase in both breadth and depth of knowledge in the science curriculum made us think hard about what we needed to do to ensure students could deepen their learning rapidly. We decided that they needed to 'recall' the science knowledge rather than rely on being told again, or looking something up, or re-reading it from somewhere. We worked in very close collaboration in deciding the key science knowledge all students required. We produced knowledge organizers to use with students and introduced retrieval quizzes at the start of our lessons. Consequently, we have noticed a transformation in the quality of student discussion. They are increasingly keen to know 'stuff'. And they are increasingly keen to learn because they have got something to hang the new knowledge on already.

We also focused on sequencing, making sure that students appreciate how the current knowledge they are learning links to what they have learned before and to what is coming up next. Our ultimate question to students is, 'How is what you are learning *now* going to enable you to learn in the future?' That is very challenging because it is hard for somebody to say what they are going to know without knowing it. Although they might not know, they often come to classes wanting to discuss science that is incredibly complex, because a lot of what they see in the media is incredibly complex science; whether it is David Attenborough or Professor Brian Cox or the Mars Rover Landing, they arrive in class and begin asking questions. I say to them, 'Well, if you want to learn that, then you need to do this first.' They then see a purpose to things that they would have perceived as not being as interesting and they realise they are going to be able to find out the answer to the questions they had when they entered the room.

The core of the biology curriculum

There are several pathways that run through the biology curriculum: cell biology and organisms, their structure, how cells form tissues, and the hierarchy of organisms, is a meaty pathway that runs through the whole curriculum. And you then explore different body systems: the respiratory system and the digestive system. The bioenergetics pathway is a substantial one that includes respiration and photosynthesis, which branch off into many different areas. There is also contextual knowledge that they might need to think about those and where they then influence other areas of biology. I think those have been two of the key areas.

One section that we have not found a place for is a unit on skeleton and muscles. It links to respiration and mitochondria in muscle cells because they release energy to contract to exercise, but you do not really go beyond that. We did not want students to miss the opportunity to learn about the skeleton and muscles, because it is incredibly important for them to know how their bodies work in more detail. We have enrichment activities that include all subject areas. Year 7 have an enrichment day in science. For this, we do some project work with them on the skeleton and muscles and get them building models and to demonstrate how antagonistic muscle pairs work. We find that it connects them well with their PE learning so that it becomes a cross-curricular link, rather than one that sits explicitly within science.

What would you like from your senior leader line managers to help you develop the curriculum?

I think it is all about asking the right questions and then being able to say, ‘So why have you put this in this order?’ To start with, I can elaborate and tell them the storyline, tell them the learning pathway that is going to take place. And then, ‘Why have you done that?’ So, they challenge my thinking, to explain our decisions. I often find that if I talk to somebody out of specialism who might not know certain things that we take for granted, they are more likely to say to me, ‘But hang on a minute, how can they do that without that?’ which we might have just made assumptions about. It shows the interest that they are taking in our subject, which is incredibly important.

I feel very fortunate knowing that my line manager is somebody who is very open to these sorts of discussions; it really is just a two-way thing. We have this huge mutual respect that I would look to my line manager, to respect me as the expert in that subject area, in the same way as I respect them as being knowledgeable in how to lead the school. No question is an idiot question, because as a senior leader you want to understand your team better and your curriculum more deeply. If you do not know, you must ask.

Biology: background

Biology was identified as a distinct field of enquiry in the 19th century, but it has its origins in early medicine and natural history from the ayurvedic and ancient Egyptian medicine, through the insights of Aristotle and Galen. The field was extended by the work of Muslim scholars, including Avicenna and later by Vesalius, Harvey, Linnaeus, and Buffon.

It is worth quoting the purpose of science from the national curriculum programme of study:

> A high-quality science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics. Science has changed our lives and is vital to the world's future prosperity, and all pupils should be taught essential aspects of the knowledge, methods, processes and uses of science. Through building up a body of key foundational knowledge and concepts, pupils should be encouraged to recognise the power of rational explanation and develop a sense of excitement and curiosity about natural phenomena. They should be encouraged to understand how science can be used to explain what is occurring, predict how things will behave, and analyse causes.[1]

The national curriculum for science aims to ensure that

> all pupils develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics; develop understanding of the nature, processes and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them; are equipped with

1 www.bit.ly/2TU3Mkq

> the scientific knowledge required to understand the uses and implications of science, today and for the future.

Once the importance statements have been revisited, it is helpful for subject leaders and coordinators to discuss and agree with colleagues the reason why their subject, in this case, science, is important for the pupils in their school. One way of doing this is to draw on a quote, in this case from Elon Musk: 'It is important to view knowledge as sort of a semantic tree – make sure you understand the fundamental principles, i.e., the trunk and big branches, before you get into the leaves/details or there is nothing for them to hang on to.' This kind of prompt allows us to formulate our way of stating the importance of the subject. We might agree or disagree with such a statement and, in doing so, come to a form of words that expresses our view of the importance of this subject, in this school. This moves us away from the territory of 'We teach this subject because of the SATs or GCSEs.' While the external tests and exams are important, they are not the totality of the subject.

Professional communities

Subject associations are important because at the heart of their work is curriculum thinking, development and resources. The subject association for science is the Association for Science Education. Any member of staff with responsibility for a subject should be a member of the relevant subject association, and this should be paid for by the school.

Twitter subject communities are important for the development of subject knowledge because it is here that there are lively debates about what to teach, how to teach and the kinds of resources that are helpful. For science, it is worth following ASE on Twitter and the hashtags #ASEchat, #scichat, #stem, #primaryscience, #ChatBiology, #ChatChemistry and #ChatPhysics.

LINKS

The Wellcome Trust – www.bit.ly/2VvTgAz
Explorify – www.explorify.uk/our-story
STEM resources – www.bit.ly/37ozHMY
The Association for Science in Education – www.ase.org.uk/home
Primary Science Quality Mark – www.psqm.org.uk/what-is-psqm
NASA – https://go.nasa.gov/2VjsThy
Core Knowledge – www.coreknowledge.org.uk/science.php

An overview of the Bottisham Village College's key stage 3 science curriculum

An inspiring science education provides the foundations for understanding the wonders of the natural world and amazing achievements of humans through the specific disciplines of biology, chemistry and physics. Students need a good grounding in the essential aspects of the knowledge, methods, processes and uses of science. They are encouraged to develop a sense of excitement and curiosity about natural phenomena and to understand how science can be used to explain what is occurring, predict how things will behave, and analyse causes.

As shown in the teaching sequence below, the topics are sequenced in such a way that they 'spiral' over the long term from one year to the next, but are also ordered so that within each year cross-specialism topics support one another. For example, understanding energy stores in Year 7 Energy before learning about the function of mitochondria in Year 7 Cell Biology.

Disciplinary knowledge is woven throughout every topic with students developing mathematical and working scientifically skills in different contexts; these have increasing levels of challenge as students progress on their learning journey through the curriculum.

Year 7 Taught by either one teacher or split between 2 teachers ensuring key concepts continue in sequence.	Year 8 Taught by either one teacher or split between 2 teachers ensuring key concepts continue in sequence.	Year 9 Topics split between two teachers and taught on rotation of first and second bio/chem/phys topics then third and fourth topics.
Energy • Energy stores; transfer pathways; energy resources.	Atomic Structure and the Periodic Table • Atoms, elements, and compounds; atomic structure; periodic table structure; properties of group 1 and 7; chemical formulae.	**Biology** Cell Biology • Eukaryotic and prokaryotic cells; types of microscope; cell differentiation; factors affecting diffusion.
Particle Model • Particle arrangement solids, liquids, gases; changes of state; particle motion; purity.	Energy • Conduction, convection, and radiation; power; conservation of energy; efficiency.	Organisation • Digestive system; circulator and respiratory systems; blood; CHD; plant tissue and organ functions.

Cell Biology • Cell structure; organelle functions; specialised cells; hierarchy of organisation; microscopy.	Ecology • Adaptations; competition; food chains and webs; predator/prey cycles.	Infection and Response • Bacterial, viral, fungal and protist diseases; disease transmission and prevention; how pathogens make people feel ill; non-specific and specific defence systems in humans.
Homeostasis and Response • Human and plant reproductive systems; menstrual cycle; fertilisation and pregnancy.	Electricity and Magnetism • Current in parallel circuits; resistance and current; electromagnets.	Bioenergetics • Photosynthesis; aerobic and anaerobic respiration.
Forces • Types of force; effects of forces; reaction force; gravity; resultant force.	Chemical Changes • Conservation of mass; reactions of metals; gas tests; displacement reactions; extracting metals.	**Chemistry** Atomic Structure and the Periodic Table • Mixtures; separation techniques; relative atomic mass; evolution of the periodic table; evolution of the model of the atom; patterns in group 1 elements.
Properties of Matter • Physical and chemical properties of matter; separation techniques; solubility.	Organisation and Bioenergetics • Respiration; effect of exercise; gas exchange and diffusion.	Bonding, Structure and Properties of Matter • Ionic bonding; covalent bonding; metallic bonding.
Organisation • Healthy diet; deficiency diseases; drugs; digestive system; enzymes.	Forces • Speed; resistive forces; acceleration; pressure	Quantitative Chemistry • Conservation of mass; relative formula mass; uncertainty.
Electricity and Magnetism • Circuit symbols; series and parallel circuits; current; magnetic poles; magnetic fields.	Chemistry of the Atmosphere and Using Resources • Fossil fuels; composition of the atmosphere; carbon cycle; climate change; recycling; potable water.	Chemical Changes • Metal oxides; reactivity series; formation of soluble salts; reduction and oxidation;
Chemical Changes • Physical and chemical changes; acids and alkalis; neutralisation; combustion; thermal decomposition.	Inheritance, Variation and Evolution • Variation; structure of DNA; species; biodiversity; species survival; theories of evolution.	Energy Changes • Endothermic and exothermic reactions; reaction profiles.

Bioenergetics • Leaf structure and function; photosynthesis; factors affecting photosynthesis; transpiration.	Waves • Light; reflection; refraction; eclipses; colour; the eye.	**Physics** Energy • Dissipation of energy; calculating Ek, Ep and Ee, evaluating energy resources.
Waves • Types of waves; properties of waves; auditory range; the ear.		Electricity • Current, potential difference and resistance; Ohm's law; three core cable in appliances; power.
		Particle Model of Matter • Density; particle motion in gases; internal energy and changes of state.
		Atomic Structure • Evolution of the model of the atom; Isotopes; types of radioactive decay; uses of radiation.

Three documents for your senior leader line manager to read about science

1. *Powerful Ideas of Science and How to Teach Them* by Jasper Green.
2. *Cracking Key Concepts in Secondary Science* by Adam Boxer, Heena Dave and Gethyn Jones.
3. KS1/2, 3 and 4 Science Programmes of Study.

Five questions for your senior leader line manager to ask you about science

1. How does science embody the whole school curriculum intent and contribute to the holistic education of each student?
2. What should a student know, understand, and be able to do in science when they begin Year 7?
3. What orders are topics sequenced in? Why?
4. What are the threshold concepts and key concepts in science?
5. How are substantive and disciplinary knowledge brought together and taught in science?