Making every science lesson count

Six principles to support great science teaching

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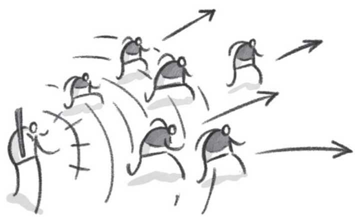
Introduction

Science teachers have a huge responsibility – we shape the future of society by developing the thinking and understanding of the next generation of scientists. Science is a vast body of ever-growing knowledge and skills which can prove daunting to students and new science teachers alike. Great science teachers have helped to develop that knowledge through their passion for and commitment to the subject. It is this that helps them to enthuse their students. Over the years, I have been fortunate enough to work with and learn from a number of great science teachers – science teachers who are passionate about their subject and know how to impart the joy of science to their students.



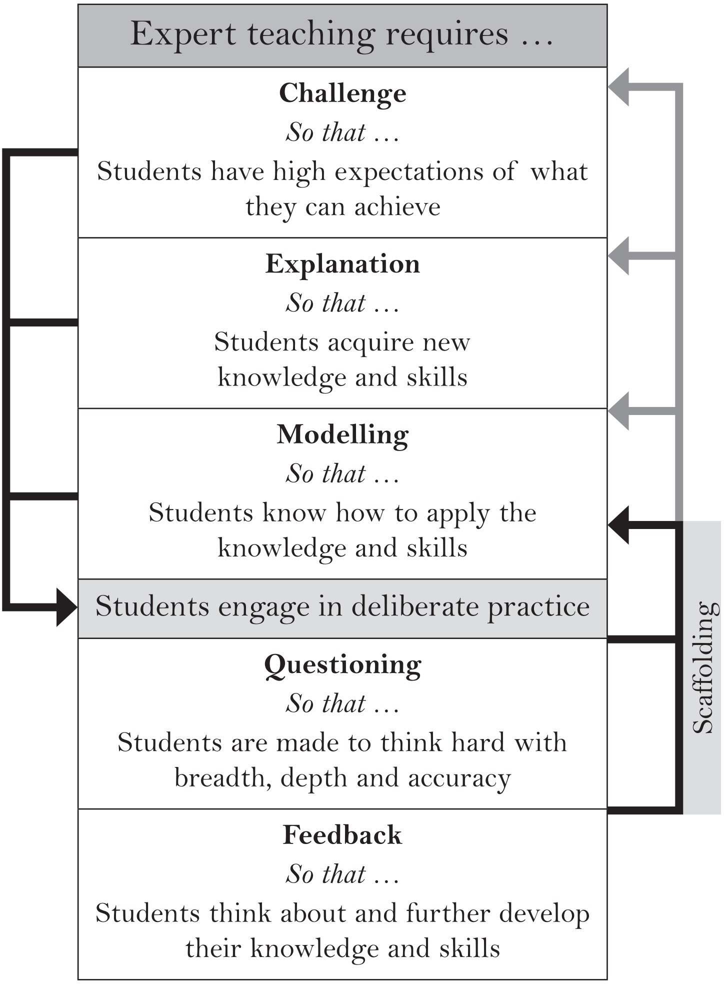
One such teacher was Pam McCulloch, a science teacher at Durrington High School. She started working at the school in 1978, and she taught there until her retirement from full-time teaching in 2014. Over this thirty-six year period, Pam's students consistently achieved fantastic outcomes and many of them went on to brilliant and successful careers within the field of science. Very few teachers achieve this level of excellence over such a long and distinguished career. Pam was an excellent teacher and has very clear views about why science teaching matters. In May 2016 she told me:

To me, science is the most important subject. All other subjects pale in its wake. As science teachers, it is our responsibility to enthuse the pupils so that each generation pushes the *boundaries of scientific discovery further and further. This is essential for the continuing advancement of humankind. Without science, we would still be in the caves.*

A good science education provides students with the knowledge they need to think deeply about the medical, technological, environmental and industrial problems that will need to be solved over the next century. It builds on our inquisitive nature about the world in which we live and makes us question things, and by questioning we solve problems and advance our own understanding of the world. Even for those students who do not go on to pursue a career in science, it is essential that they have an understanding of how science impacts on their lives. How else can they make informed decisions in an increasingly technological world? Science is the perpetual search for understanding and explanation, and this starts in school science lessons.

In *Making Every Lesson Count*, Andy Tharby and I describe six pedagogical principles that lay at the foundations of great teaching.[1] The first principle, *challenge*, is the driving force of teaching. Only by giving our students work that makes them struggle, and by having the highest possible expectations of their capacity to learn, will we be able to move them beyond what they already know and can do. Challenge informs teacher *explanation*, which is the skill of conveying new concepts and ideas. The trick is to make abstract, complex ideas clear and concrete in students' minds. It is deceptively hard to do well. The next principle is *modelling*. This involves 'walking' students through problems and procedures so that we can demonstrate the steps and thought processes they will soon apply themselves. Without *practice* student learning will be patchy and insecure. They need to do it, and they need to do it many times, as they move towards independence. It goes without saying

1 Shaun Allison and Andy Tharby, *Making Every Lesson Count: Six Principles to Support Great Teaching and Learning* (Carmarthen: Crown House Publishing, 2015).


Expert teaching requires …
Challenge
So that …
Students have high expectations of what they can achieve
Explanation
So that …
Students acquire new knowledge and skills
Modelling
So that …
Students know how to apply the knowledge and skills
Students engage in deliberate practice
Questioning
So that …
Students are made to think hard with breadth, depth and accuracy
Feedback
So that …
Students think about and further develop their knowledge and skills
Scaffolding

that practice is the fulcrum around which the other five strategies turn. This is because it develops something that is fundamental to learning – memory. Students need to know where they are going and how they are going to get there. Without *feedback*, practice becomes little more than task completion. We give students feedback to guide them on the right path, and we receive feedback from students to modify our future practice. And so the cycle continues. The last principle is *questioning*. Like explanation, questioning is a master art. It has a range of purposes: it allows us to keep students on track by testing for misconceptions and it promotes deeper thought about subject content.

Great science teaching is aligned with all of these principles; however, they are not a lesson plan or a tick-list. This book will present them as individual entities, but in reality they are members of one body. They sustain each other. Not only do they help you to plan science lessons and schemes of work, but they also help you to respond with spontaneity to the ever-changing and ever-complex needs of your students within lessons.

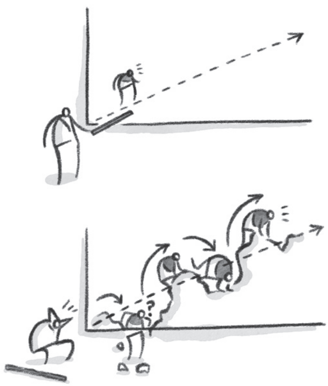
In recent years, the education establishment has lionised the individual lesson. Indeed, teachers have been enculturated to talk about teaching in terms of how successful or unsuccessful a single lesson has been. The issue of the single lesson, and in particular the ubiquitous three part lesson, probably came about as a result of the following:

- The National Strategies. From 1997 to 2011 the Department for Education produced training materials that were delivered to schools, with a significant focus on the three part lesson.[2]
- The history of Ofsted and schools grading lessons. Although this is now no longer the practice of Ofsted and, thankfully, many schools.

2 Department for Education, *The National Strategies 1997–2011* (2011). Available at: https://www.gov.uk/government/publications/the-national-strategies-1997-to-2011.

- The publication of national curriculum schemes of work and their adherence to the three part lesson idea.[3] The legacy of this is still seen within a number of commercially published science schemes of work.

The problem with this focus on the individual lesson is that learning science is not speedy, linear or logical. It is slow, erratic and messy, and it doesn't fit into neat three part chunks. Fortunately, though, there is something that we can use to our advantage. When we explain new scientific ideas, students have a great deal of prior knowledge to build upon. For example, children know that if they hold something in the air and drop it, then it will fall towards the ground. They understand the fundamental principle of gravity. We can exploit this, and then build upon it through our teaching. There are a whole host of real life examples that we can use to supplement our explanations.



Cognitive science tells us about the importance of storytelling when it comes to supporting good explanations, which is why great science teachers are great storytellers![4] We don't just tell them about the theory of evolution, we tell

3 See http://webarchive.nationalarchives.gov.uk/content/20100612050234/http://www.standards.dfes.gov.uk/schemes3/subjects/?view=get.

4 See Daniel T. Willingham, *Why Don't Students Like School? A Cognitive Scientist Answers Questions About How the Mind Works and What It Means for the Classroom* (San Francisco, CA: Jossey-Bass, 2010), p. 66.

them about Darwin's journey around the Galapagos Islands on the *Beagle* and how he started to observe the different beaks of the finches and how this made him consider how these changes came about by the process of natural selection. We hook them in with a story and then hang the theory around it.

Then, of course, there is the practical work and demonstrations that we do. Again, they lend themselves brilliantly to supporting great explanations, but they are also an essential part of the modelling work we do, which is how we make abstract ideas concrete. For example, once a student has been shown potassium permanganate crystals dissolving and producing a purple streak which, when heated, moves around water in a convection current, understanding the idea of convection becomes so much easier. It also makes it more memorable.

Real life examples can also be used to support the idea of making the abstract more concrete. For example, the theoretical explanation of plate tectonics is quite a challenging concept to understand. However, by linking it to videos and images of erupting volcanoes, earthquakes and tsunamis, we can help students to understand these abstract concepts. This also exploits our inquisitive nature as humans. By showing students videos and images of natural processes they instinctively want to find out what causes them.

John Hattie proposes that there is a difference between surface and deep learning.[5] Simply speaking, surface learning refers to knowing the key facts about a topic, whereas deep learning refers to how we are able to relate, link and extend this knowledge. It's clear to see how this idea is crucial to the teaching of science. For example, once students understand the particle nature of solids, liquids and gases (surface learning), they can use this to explain processes such as melting, evaporation, condensation and convection (deep learning).

5 John Hattie, The Science of Learning. Keynote speech presented at Osiris World-Class Schools Convention. London, 2014.

The most skilled science teachers are able to judge perfectly how much time to spend on the surface learning before challenging the class to move on to the deep learning. They understand that there is no point in introducing the deep learning if students are not secure with the surface learning, which also supports effective questioning and feedback.

The six principles are already inherent in the best science teaching. Unfortunately, however, there are a number of challenges for science teachers to overcome. It's worth exploring these one at a time.

High level of content

The science curriculum is packed with content that teachers have to get through at an alarming rate. We know that in order to learn something, a student needs to focus on repetition and retrieval practice (i.e. retrieving items of knowledge from memory over and over again). As science teachers have to move quickly from one topic to the next, to the next, there is very little opportunity to return to key ideas to embed them. It takes lots of practice time to embed key knowledge and skills – a luxury that science teachers simply don't have.

Abstract ideas

Science teachers have to explain a number of abstract ideas that their students can't perceive with their senses. For example, an atom is a very theoretical concept. If students are going to understand what it is and all of the ideas beyond it, such as chemical bonding and the particle nature of matter, then they have to begin by developing their own concrete understanding of a very abstract idea. This makes explanation very tricky.

The tipping point between surface and deep learning

The structuring of learning in science is difficult. We have already discussed the idea of surface and deep learning. While this potentially presents a nice framework around which to build scientific understanding, it can often have the opposite effect. Science teachers will often move on to the deep learning without really embedding the surface learning, which will inevitably result in misunderstanding, confusion and frustration. For example, particle theory is a threshold concept in science – that is, a key piece of knowledge that must be understood in order to make sense of more complex scientific ideas. It is not uncommon for students to have a basic knowledge of the facts (surface learning) but still not be able to get through the threshold because they bring with them naive interpretations and misconceptions based on cognitive misapprehensions of both a conceptual and perceptual nature. For example, many students have a basic understanding of the particle arrangement in solids, liquids and gases, but still have major misconceptions, such as believing that there are gaps between the particles in a liquid. As a result, they may be able to answer superficial questions correctly, while possessing a very limited understanding of particle theory.

Science teachers need to employ effective ways of finding out if the surface knowledge is embedded before they move on. The most skilled teachers support students in developing deep learning by:

- Using diagnostic questioning.
- Addressing non-relevant ideas in a very explicit way.
- Using pictures and models to support their explanations.
- Reinforcing key ideas at every opportunity in other science topics.

These are all strategies that will be explored in later chapters.

Fixed mindset

Carol Dweck proposes that people have a tendency for either fixed or growth mindset thinking, but in reality we are probably all a combination of both. You could have a predominant growth mindset in one area but there can still be things that trigger you into fixed mindset thinking.[6] A fixed mindset means that students believe their intelligence is fixed and cannot be developed. A growth mindset means that students believe their intelligence can be developed through hard work and effort. In terms of our subject, a number of students hold the belief that they are 'not very good at science'. If you add to this the dreadful gender stereotypes that exist (e.g. 'boys are better at physics than girls') then we have a big problem. Dispelling these myths is a significant challenge for science teachers. If we are going to challenge students and raise their aspirations of what they can achieve, the first step is to make them believe that this is possible.

6 Carol Dweck, *Mindset: Changing the Way You Think to Fulfil Your Potential* (London: Robinson, 2006).

Misconceptions

Over the years, students will have picked up a number of incorrect 'facts' based on inaccurate scientific thinking and understanding; this is a huge issue for science teachers, as these mistakes compound misunderstanding when we try to develop their thinking further. For example, if a student believes that heat simply rises then they will not be able to understand the idea of convection currents, as they will not link heat transfer to changes in the density of the fluid. Scientific misconceptions are picked up and embedded all around us (e.g. we go to a supermarket and 'weigh' something in kilograms instead of newtons). This hinders our explanations. We need to identify and unpick these misunderstandings before we can build up and develop their knowledge.

Subject knowledge

Most science teachers who teach in the UK will be expected to teach biology, chemistry and physics, even though they will likely have specialised in only one of these disciplines during their higher education. The Sutton Trust's 2014 report, *What Makes Great Teaching?*, lists subject knowledge as one of the main characteristics of great teaching.[7] This presents a dilemma for science teachers. How can we stretch and challenge all students, through effective questioning and modelling, when we are teaching outside of our specialism?

7 Robert Coe, Cesare Aloisi, Steve Higgins and Lee Elliott Major, *What Makes Great Teaching? Review of the Underpinning Research*. Project Report (London: Sutton Trust, 2014). Available at: http://www.suttontrust.com/wp-content/uploads/2014/10/What-makes-teaching-great-FINAL-4.11.14.pdf.

Writing in the practical, engaging style of the award-winning *Making Every Lesson Count*, Shaun Allison returns with an offering of gimmick-free advice that combines the time-honoured wisdom of excellent science teachers with the most useful evidence from cognitive science.

Making Every Science Lesson Count is underpinned by six pedagogical principles – challenge, explanation, modelling, practice, feedback and questioning – and provides simple, realistic classroom strategies that will help teachers make abstract ideas more concrete and practical demonstrations more meaningful.

In an age of educational quick fixes, GCSE reform and ever-moving goalposts, this precise and timely book returns to the fundamental question that all science teachers must ask: 'What can I do to help my students become the scientists of the future?'

Suitable for science teachers of students aged 11–16 years

This is a book for all science teachers, no matter whether they are very experienced heads of science or science teachers starting out in their careers.

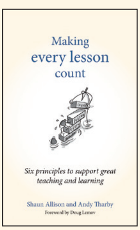
Dr Brian Marsh, Principal Lecturer, University of Brighton

Shaun has a brilliant way of synthesising complex research on pedagogy and cognitive science. His writing is accessible and is brought to life with inspirational anecdotes and stories.

David Weston, CEO, Teacher Development Trust

Shaun Allison shares the insights of an experienced classroom practitioner who takes tried-and-tested teaching and learning strategies, known to and used by experienced teachers of science, and adds pedagogical significance to them.

Dr Lyn Haynes, Senior Lecturer, Canterbury Christ Church University, Programme Director, INSPIRE STEM PGCE



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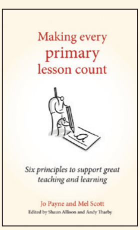

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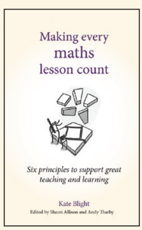

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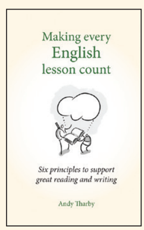

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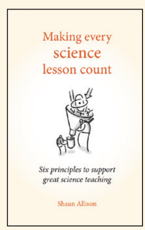

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Shaun Allison started teaching science in West Sussex, before becoming a head of science. He is currently deputy head teacher at Durrington High School. He leads on CPD and is interested in supporting teachers to grow and develop their classroom practice. He is also a popular speaker. **@shaun_allison**

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