Powerful Ideas of Science and How to Teach Them

A bullet dropped and a bullet fired from a gun will reach the ground at the same time. Plants get the majority of their mass from the air around them, not the soil beneath them. A smartphone is made from more elements than you. Every day, science teachers get the opportunity to blow students' minds with counter-intuitive, crazy ideas like these. But getting students to understand and remember the science that explains these observations is complex. To help, this book explores how to plan and teach science lessons so that students and teachers are thinking about the right things – that is, the scientific ideas themselves. It introduces you to 13 powerful ideas of science that have the ability to transform how young people see themselves and the world around them.

Each chapter tells the story of one powerful idea and how to teach it alongside examples and non-examples from biology, chemistry and physics to show what great science teaching might look like and why. Drawing on evidence about how students learn from cognitive science and research from science education, the book takes you on a journey of how to plan and teach science lessons so students acquire scientific ideas in meaningful ways.

Emphasising the important relationship between curriculum, pedagogy and the subject itself, this exciting book will help you teach in a way that captivates and motivates students, allowing them to share in the delight and wonder of the explanatory power of science.

Jasper Green has worked in science education for over ten years as a teacher, head of science and most recently in initial teacher education. He is founder of thescienceteacher.co.uk and can be found on Twitter @sci_challenge.

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Figure 15.6 Ways students and teachers receive feedback from a task; feedback is represented by lines with arrows

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About the author

Jasper Green has worked in science education for over ten years as a secondary teacher, head of science, and science lead for Ark Schools. Most recently he has been working on initial teacher education and MA programmes at the UCL Institute of Education.

Jasper studied biological sciences at the University of Oxford and later gained his PhD from the University of York. He has an MA in science education from King's College London which, together with his passion for science, social justice and teacher education, prompted him to write this book. Jasper is found on Twitter @sci_challenge and is also founder of thescienceteacher.co.uk – a website providing science teachers with free resources and ideas for the classroom.

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I want to start by thanking Frances Myers. She first showed a dyslexic 13-year-old, placed in a bottom set for science, the joy that learning biology brings. But perhaps more importantly than that, she showed me the positive difference teachers make.

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And last, but by no means least, thank you to friends and family who have supported and

encouraged me, always making sure I laughed along the way. This book is dedicated to you.

Introduction
Thinking about the right things

It was a blazingly hot afternoon and I was waiting apprehensively in my lab coat for Year 7 to arrive. 'Today we are learning about energy and food'. After fielding numerous questions about 'are we doing a practical today, sir?' and 'why are you dressed as a doctor?' we were ready to begin. Students busily completed a worksheet matching up key words before proudly declaring they were 'finished!' Unable to think of a suitable stretch question to keep them busy, I swiftly moved on to explain the experiment. Students made a dash for the apparatus and began setting fire to various snacks which were then used to warm boiling tubes containing too much water. As Pringles were plunged into the roaring Bunsen flame, hot oil started dripping down their heating needles causing a serious risk of burning, not to mention dissipation of energy. Black smoke filled the air as smouldering crisps lay abandoned on the bench. 'That stinks!' coughed one student. With a glance to the back of the room, even my university tutor had stopped writing.

Looking back at this lesson, I made a number of mistakes, such as a failure to establish routines and relationships and activity-focused planning with no thought to what students were actually doing. Fundamentally, this lesson failed because the students and I were thinking about the wrong things. That is, students were thinking about eating Pringles, dripping oil and who could finish the task first, and I was thinking about managing behaviour, distributing equipment and not setting off the fire alarm.

This book seeks to address some of these mistakes by exploring how to plan and teach science lessons so that students and teachers are thinking about the right things – that is, the scientific ideas themselves. Scientific ideas are powerful ideas because they give young people powerful ways of seeing the world that are dramatically different from their everyday experiences. Plants get their food from the air around them, not the soil beneath them; objects move even when no force is acting and mass is always conserved when paper burns.

But this scientific perspective involves more than just a knowledge of the facts of science (the substantive knowledge), it also requires young people to understand how these scientific ideas became established in the first place. It is through understanding the relationship between the scientific ideas and the nature of science that students come to appreciate science as a discipline of inquiry, which enables them to ask and answer

questions of the world such as where humans came from, why there isn't yet a cure for cancer and why coldness doesn't exist. Indeed, it is by thinking about how and why scientific knowledge becomes established that students come to see its limitations. That is, scientific knowledge is tentative, subjective and driven, in part, by progress in technology and human ambition that has both positive and negative consequences for society.

But therein lies the challenge, as it is because scientific ideas and practices are radically different from intuitive, everyday thinking that they can be hard to learn and tricky (but wonderful) to teach. This means that if we are not careful, only some young people will have access to this knowledge and even fewer will understand its significance to their own lives. Science teachers then must become experts in what they do, so they can help *all* students to acquire these abstract ideas in meaningful ways.

At the heart of this teacher expertise lies deep subject knowledge, and so each chapter provides the opportunity to develop an understanding of one scientific idea and how to teach it. Scientific ideas are introduced, one chapter at a time, in a way that will support progression in your own understanding of biology, chemistry and physics as you move through this book. Alongside the subject knowledge sit ideas of how to teach it. These ideas are based on my own experience, working in schools and in initial teacher education, but the greatest source of inspiration has come from watching other teachers teach and seeing how their students learnt. Where possible, I have linked strategies to research so that you can better understand the rationale as to why these ideas may, or may not, work in your classroom. By using research in this way, I hope to convey some of the intellectual vibrancy that teaching science brings and encourage you to engage with these and other ideas as you develop your own philosophy of what it means to teach science well. You can find further ideas and resources, shared by many teachers, on my website – thescienceteacher.co.uk.

Whilst I am not teaching in classrooms at the moment, I have chosen to refer to 'we' throughout the book to create a sense that *we* are on a journey together. Please forgive me if it sounds disingenuous at times, but I hope the overall style makes for an easier read.

There are five sections to this book that you will encounter along the way. Section 1 looks at some of the aims of science education. In Chapter 1, we move beyond seeing science from a functional perspective, that is, for creating more scientists or knowing how to wire plugs, to seeing science as a body of specialised knowledge and a tradition of inquiry that can transform how young people see themselves and the world around them. Then, by introducing you to 13 powerful ideas of science in Chapter 2, I hope to frame science as a discipline of related, but distinct, ideas that provide the substance through which young people can ask and answer interesting and important questions that matter to them. Whilst each powerful idea in this book is a substantive idea, such as evolution by natural selection or gravity being a force of attraction between all objects, running through each of these ideas sit many opportunities to explore the nature of science. Powerful ideas then provide an education into both the substantive *and* disciplinary ideas of science and to do one without the other is to misrepresent what science is.

Section 2 considers how teachers can help students to acquire scientific ideas in a meaningful way and so requires us to recognise that knowledge is more than just information. We look at some of the distinguishing features of scientific knowledge that

make learning science tricky in the first place, before exploring in more detail how we learn, drawing on ideas from cognitive science. But learning science (and doing science) involves emotion too, and so we explore some of the affective aspects that play important roles in initiating and sustaining learning in the science classroom.

Taking what we know about how and why students learn science, Section 3 looks at how to approach the complicated business of planning science lessons by thinking about the '*what*', the '*how*' and the '*form*' of lesson planning. The *what* identifies what we want students to learn and do. The *how* takes the *what* and transforms it into something students can experience, discuss and think about. This involves thinking about the *best* ways to represent and portray ideas and so involves an appreciation of the important relationship between curriculum, pedagogy and the subject itself.

Then, taking the *what* and the *how*, we consider the form of lesson planning that introduces you to the six phases of instruction. The *form* looks at ways to introduce scientific ideas without overloading students by building upon prior knowledge and focusing attention on the important bits using carefully designed demonstrations. By allowing time for practice and application, students then refine their scientific understanding and start to integrate this scientific perspective into their lives so they can see the wonder in the everyday. These six phases of instruction are explored in Section 4 in more detail using a number of examples and non-examples so that we can consider what works (and doesn't work) in the classroom and why. Finally, because students won't always learn what we intended them to, Section 5 explores what responsive science teaching looks like so that we can respond and try again.

So, hold on tight as we begin our journey into the powerful ideas of science and how to teach them.

Section 1

Aims for school science education

For whom and for what?

CHAPTER

1 Fallacies of science education

At 8:15 am on 6 August 1945, the first atomic bomb used against human beings exploded over the Japanese city of Hiroshima. The bomb, packed full of uranium-235, exploded 600 metres above the city as two pieces of uranium were catapulted into each other, creating a super-critical mass of radioactive material that initiated a chain reaction. Vast amounts of energy were released as uranium-235 atoms split apart by nuclear fission, creating temperatures on the ground that fused metal and melted glass. By the end of 1945, 140,000 people had died (Figure 1.1), but many more would go on to endure the horrific consequences of radiation poisoning. Whilst the atomic bomb was a weapon of war, it was also a product of science.

Figure 1.1 The tricycle of Shinichi Tetsutani (then 3 years and 11 months) who died on 6 August 1945

Note: This tricycle was initially buried with Shinichi at home. Forty years later, Shinichi's remains were transferred to the family grave and the tricycle was donated to

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