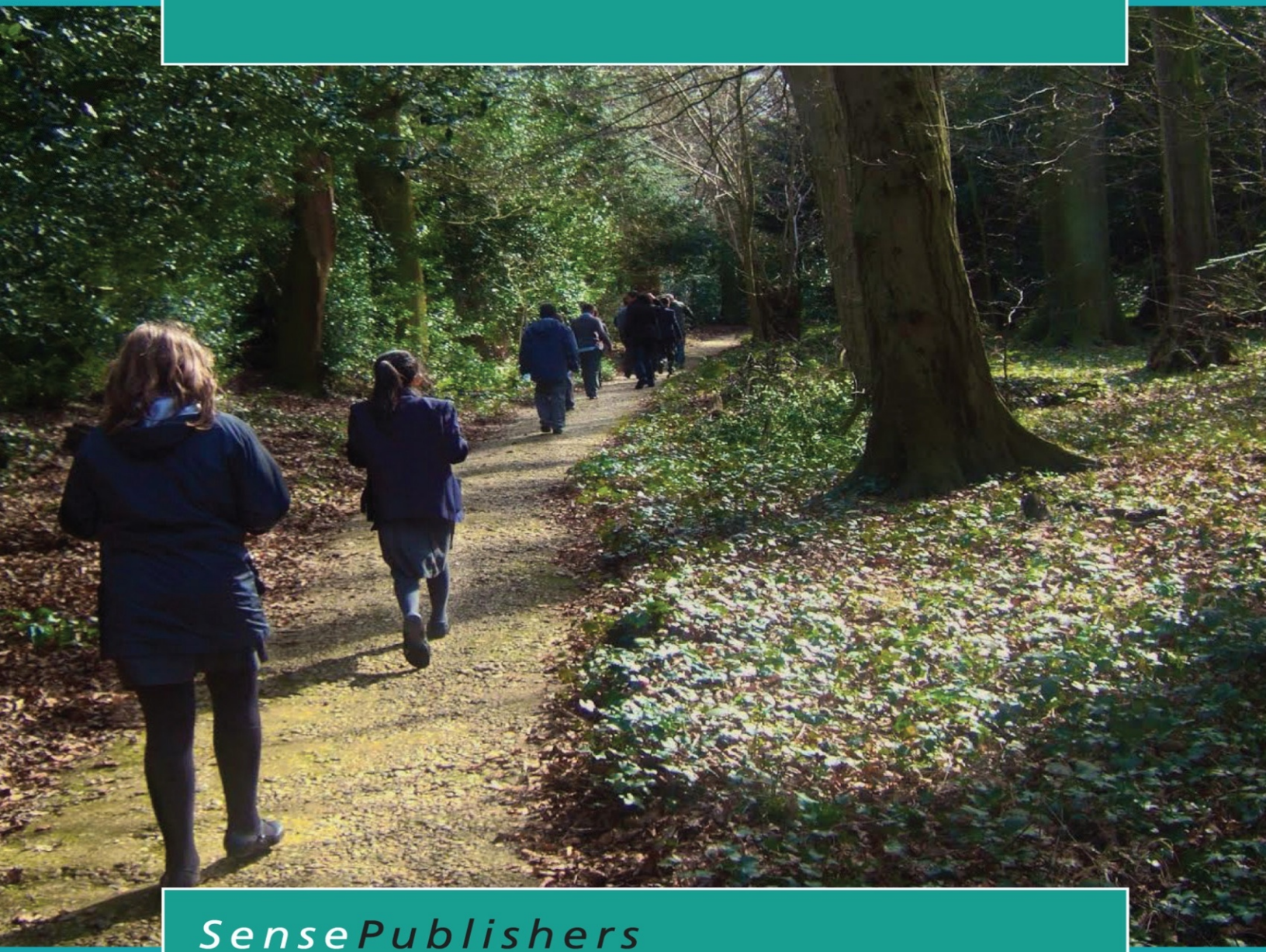
NEW DIRECTIONS IN MATHEMATICS AND SCIENCE EDUCATION

Darwin-Inspired Learning

Carolyn J. Boulter, Michael J. Reiss and Dawn L. Sanders (Eds.)



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Darwin-Inspired Learning

NEW DIRECTIONS IN MATHEMATICS AND SCIENCE EDUCATION

Volume 28

Scope

Mathematics and science education are in a state of change. Received models of teaching, curriculum, and researching in the two fields are adopting and developing new ways of thinking about how people of all ages know, learn, and develop. The recent literature in both fields includes contributions focusing on issues and using theoretical frames that were unthinkable a decade ago. For example, we see an increase in the use of conceptual and methodological tools from anthropology and semiotics to understand how different forms of knowledge are interconnected, how students learn, how textbooks are written, etcetera. Science and mathematics educators also have turned to issues such as identity and emotion as salient to the way in which people of all ages display and develop knowledge and skills. And they use dialectical or phenomenological approaches to answer ever arising questions about learning and development in science and mathematics.

The purpose of this series is to encourage the publication of books that are close to the cutting edge of both fields. The series aims at becoming a leader in providing refreshing and bold new work—rather than out-of-date reproductions of past states of the art—shaping both fields more than reproducing them, thereby closing the traditional gap that exists between journal articles and books in terms of their salience about what is new. The series is intended not only to foster books concerned with knowing, learning, and teaching in school but also with doing and learning mathematics and science across the whole lifespan (e.g., science in kindergarten; mathematics at work); and it is to be a vehicle for publishing books that fall between the two domains—such as when scientists learn about graphs and graphing as part of their work.

Darwin-Inspired Learning

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Cover picture: 'Going for a thinking walk' – students on Charles Darwin's Sandwalk at Down House. © IntoUniversity

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ROSEMARY & PETER GRANT

FOREWORD

Through the introduction of Darwin's inspirational writings, this important book, *Darwin-Inspired Learning* will create an atmosphere among students in which scientific and creative imagination flourishes. Students will be encouraged to pose their own questions and be allowed to discover their own answers through the formation of their own hypotheses and experiments. There can be no better guide to the success of this approach than an in-depth examination of Darwin's writings, his books, notebooks, and letters. Even today his writings are a pleasure to read, his descriptive passages poetic in their elegance, and his acute scientific observations and analytical logic exciting. They reveal his intense desire for a full and accurate understanding of a phenomenon by raising questions and posing explanations (hypotheses). Darwin, the writer, talks to the reader, but in fact he is talking to himself, out loud, in print.

Darwin was an exceptionally talented and acute observer, whether it was describing in detail the anatomy of a marine invertebrate, the reproductive parts of a plant, the ecology and behaviour of a bird or mammal, or an unusual rock formation. A characteristic of all his writings and particularly prevalent in his notebooks is his analytical approach when confronting a problem. Evidence is considered from all angles: the geographical location, geological formation, climatic variation, the flora and fauna, in other words the complete context of the problem. His hypotheses, always subjected to a lengthy process of deliberation and contemplation, were often followed by experiments. When experiments were not available he tried to check his ideas for consistency with other facts. And being intensely aware of the dangers of being led astray by a favoured hypothesis, he constantly questioned the implications of his findings. In his notebooks, he sometimes uses the Spanish *cuidado*, careful, as a warning when in danger of being carried away by his enthusiasm.

Another striking feature is the immaculate organisation of his field notes, especially remarkable for a man suffering constant sickness at sea, subjecting himself to long hikes over hot lava in the Galapagos and climbs up to 3700 metres in the Andes. The date and location head each page and there is a margin for afterthoughts, comments and additions.

This book comes at a propitious time. Today we face immense global challenges, both environmentally and socially. To come up with imaginative solutions to our problems we need to foster the magic of curiosity-driven research in both arts and science in our students, children and grandchildren. There is no better source of inspiration than the writings of Charles Darwin.

Rosemary & Peter Grant
Princeton University
USA

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The editors are very grateful to Karen Goldie-Morrison who kindly volunteered to copyedit the entire manuscript and did so wonderfully, to Stephen Keynes for his leadership of the Charles Darwin Trust and to the many others who have supported the Trust and helped bring this book to fruition.

RUTH PADEL

OPEN WINDOW

He's glad that she is glad. He has not publicly
rejected the idea of a Creator.

Frederick Temple, soon to be
Archbishop of Canterbury,

says you can square evolution with God.
God operates through the slow work

of natural cause. 'Even better
than making the world,' says a letter

from Charles Kingsley, novelist,
'God makes the world make itself.'

He watches her open a window, for air,
and smile at Lenny. Religion. A burned heart

in its thorns. A basket of molten glass.
A rock face shot with quartz

on which the sun shines
as it rises, lighting the rock to fire.

Down House, Kent 1860

MICHAEL J. REISS, CAROLYN J. BOULTER & DAWN L. SANDERS

INTRODUCTION

Darwin-Inspired Learning

This book is both a celebration and a clarion call. It is a celebration of all that has been done by the Charles Darwin Trust and others to enhance education by drawing on Darwin's life and ways of working. It is a clarion call because of the editors' and authors' beliefs that there is still much to be done.

There are many reasons why Darwin is an invaluable resource for curriculum and pedagogy. For one thing, of course, he is the author of *On the origin of species*, one of the most important scientific books ever produced and perhaps the only one of such importance that can still profitably be read by non-experts and experts alike. But there is more to Darwin than the theory of evolution by natural selection. While the theory of evolution features in this book, many chapters make only limited reference to it. Instead they draw on other aspects of Darwin's life and work.

While Darwin's life – his academic shortcomings at school and university, the *Beagle* voyage, his views on religion and slavery, the wealth of information we have about his large family – mean that it is relatively easy to interest students in him, it is his ways of working, along with the theory of evolution by natural selection, that make him so suitable a resource for education, especially science education.

For a start there is the fact that *On the origin of species* is really one long argument – and the importance of argumentation is increasingly recognised in education (Erduran & Jiménez-Aleixandre, 2007; Walton, 2013). Related to this is the fact that evolution as an historical science, both biological and geological, provides a useful counterbalance to the paradigm of experimental physics. While Darwin was an outstanding experimentalist, he combined this with acute powers of observation and a tremendous ability to synthesise huge amounts of information, producing general laws as a consequence. In this he was aided by a veritable army, male and female, amateur and professional, of correspondents. In addition, Darwin was a genius at devising simple instruments from household materials and in the richness with which he reported his findings, especially his book *The expression of the emotions in man and animals* (Darwin, 1872), can be said to have anticipated aspects of multi-modality by over a century.

Of course, this book is not intended as hagiography and there is always the risk of simplification when historical figures are used in science education – few science teachers or educators are experts in the history of science. Nevertheless, editing this

C.J. Boulter et al. (Eds.), Darwin-Inspired Learning, 1–12.

volume has confirmed in us the belief that, at the very least, Darwin's life and ways of working are a rich repository on which all those concerned to improve science education can draw.

The three of us have known each other for many years but the origins of this book are in the roles we have played in the Charles Darwin Trust. Carolyn Boulter and Dawn Sanders are two of the Trust's education consultants, having produced many curriculum resources and run countless workshops for the Trust. Michael Reiss is one of the Trust's trustees. The three of us were much heartened by the response we received when we approached potential contributors. Practically everyone enthusiastically agreed and produced their draft chapters in good time.

DARWIN'S HERITAGE

In Chapter 1, Randal Keynes, great-great-grandson of Charles Darwin and a trustee of the Charles Darwin Trust, provides a personal perspective on Darwin the scientist and his relevance for education. Darwin's life is traced from his time as a schoolboy through his university years, the *Beagle* voyage, his subsequent six years in London, his move with Emma to Down House, the decade spent on barnacles, his work on 'the species question' and his many years of experimentation. Keynes argues that Darwin's ways of working can be offered to students as an inspiration for an imaginative, creative and exciting approach to the life sciences in school classrooms and the world outside.

Dawn Sanders in Chapter 2 sees Down House and its surroundings as Darwin's living laboratory. Here, Darwin drew on every resource to hand – even the hair from Emma's head and whalebone (baleen) from one of her corsets. Furthermore, the outdoor, living laboratory of Downe connected Darwin not just to contemporaneous scientists but to gardeners, pigeon-fanciers and others in an extended social world. Despite his poor health, which meant that he rarely went further than he could walk in two to three hours, Sanders notes how the diversity offered by the local flora, fauna and habitats (both semi-natural and human-made) gave him opportunities to make the repeated experiments and observations needed for his work.

Cambridge University Library is home to the Darwin Correspondence Project, a unique undertaking to research and publish all of Darwin's 15,000 surviving letters. In Chapter 3, Sally Stafford describes how the project has worked in partnership with selected secondary schools to develop a series of online learning resources based on Darwin's correspondence. Through the letters we learn about Darwin as a person, his family life, his friends and peers, his ways of working, how he conducted his research and his scientific methods. As Stafford points out, the letters also show Darwin's almost child-like enthusiasm for every organism that he encountered and his enduring fascination with the natural world. Stafford provides three case studies, one in English, one in history and one in science, to show how secondary students can be both intrigued and inspired by his letters.

DEVELOPING A SENSE OF PLACE

In Chapter 4, Paul Davies, Dawn Sanders and Ruth Amos highlight the role cultivated and other outdoor landscapes can play in developing children's understanding of the living world. They discuss how these can offer access to authentic environments for science and thus provide opportunities to see and actively participate in the discourses of 'real science' by using the tools and language of specific science disciplines. Furthermore, such environments can provide creative ways of learning and thinking together, which they illustrate by a case study of a residential biology field trip. Drawing on Hodgson Burnett's *The secret garden* (undercited in science education), Davies, Sanders and Amos also argue for more space for play – both in botanic gardens and school grounds.

Ola Magntorn argues in Chapter 5 that the notion of 'reading nature', i.e. the ability to recognise organisms and relate them to other organisms and to material cycling and energy flow in a specific habitat, is central to ecology. Reading nature is therefore an important component of ecological literacy. Magntorn goes on to argue that in many ways Darwin was the first person to read nature in this way and that students too can be taught to read nature. He illustrates this with a number of case histories including one where primary school students (aged 10 to 12 years) were helped to read a river ecosystem by focusing on a small freshwater shrimp *Gammarus pulex* and its ecology. This helped the students to understand the river ecosystem by starting with a single organism and gradually building up from it.

Travelling has long been seen as a great way of finding oneself. In Chapter 6, Sandra Selles explores the teaching and learning possibilities of two projects inspired by Darwin's manuscript records of his three-month visit to Rio de Janeiro in 1832. The more recent of these projects took place in 2008 and entailed a group of teachers, science educators, scientists, journalists and students following, over four days, a journey the 23 year-old Darwin took near Rio 176 years earlier. It is clear that not only did the project help many of the people on the route to learn about Darwin and his ideas about evolution and slavery, it also helped them to appreciate the importance of these places for his thinking.

Darwin had ten children and in Chapter 7 James Moore explores how their lives were affected by their father. The children of any age seem to have childhoods that are remarkable by our standards but Charles' and Emma's were especially distinctive. All of them grew up with their father working at home, many of them during his barnacle years. 'Then where does he do his barnacles?' one of them famously enquired on visiting a neighbour but seeing no dissecting table or microscope in his study. Once the barnacles were gone, their father settled some 90 fancy pigeons into two new garden lofts. At the same time Darwin began assembling a Noah's Ark of other exotic animal breeds, or their carcases, from all over the world. Poultry, puppies, rabbits and other creatures were used to build up an encyclopaedia of evidence for his 'big book' showing that domestic and farmyard species varied. Each differed slightly from individual to individual and the differences had been artificially selected by breeders to create new 'varieties' that if

found in the wild would be classed as new species, thus mimicking natural selection. It is unsurprising that several of the boys achieved scientific distinction. The girls had the education considered appropriate at the time – very little – though Henrietta gradually became her father's in-house editor.

Darwin had a great belief in the power of observing things for oneself and in Chapter 8 Ruth Barlow demonstrates the value of this principle. While assisting in the delivery of courses with the Charles Darwin Trust, she found that students, no matter what their age, responded enthusiastically to contact with original artefacts from Darwin's life. Among the artefacts owned by the Charles Darwin Trust are many books by Darwin and his followers, scientific collections, such as Charles's own collection of beetles, and oddities like the slide that Charles had a local carpenter make to fit over the main staircase at Down House so that his children could play indoors on rainy days – which, as Barlow notes, is hardly the act of a typically stern Victorian father, which Charles certainly wasn't. Barlow goes on to show how a first edition of *On the origin of species*, whether viewed in the hand or online, can be used for teaching, as can Darwin's 'worm-stone micrometer' and his many specimens.

THE IMPORTANCE OF ACTIVE HANDS-ON ENQUIRY

In Chapter 9, Mike Corbishley reviews the ways in which evidence-based learning has developed since Darwin's time. In most schools in England at that time learning was by rote. The important subjects were the three Rs and scripture. Charles Darwin was not happy with the emphasis in the public schools (i.e. the famous fee-paying, independent schools) on classics and all but the eldest of his five sons were sent to Clapham Grammar School, which had been founded in 1834 because the headmaster was an enthusiastic supporter of the sciences. Darwin was a geologist before he was a biologist and he was well aware of developments in archaeological research, in particular the establishment of a chronology for prehistoric times based on scientific analysis and fieldwork. Corbishley goes on to show how archaeology teaching, whether in schools or outside of schools, can manifest a careful examination of evidence and respect for objects of which Darwin would have approved.

E. O. Wilson once memorably urged readers to explore the rich but often overlooked diversity of life found close at hand, as opposed to exotic locales, by taking their own 'Magellanic voyage of discovery' around the trunk of a single backyard tree. Taking a cue from Wilson, James Costa, in Chapter 10, encourages readers to emulate Darwin's voyage of discovery aboard his 'ship on the Downs' – Down House. Darwin's bustling home and its environs was his refuge and inspiration, its study, garden, meadows and woodlands the setting for an astonishing range of laboratory and field studies. As Costa says, Darwin's experiments and related observational investigations are so varied that they can be replicated, or adapted, for just about any age group and interest: behaviour, morphology, biogeography, plant growth, physiology and more.

Charles Darwin was fascinated by child development and pioneered this field with scientific observations of his own children. In Chapter 11, Stephen Tomkins and Sue Dale Tunnicliffe trace how children recognise life and then name and categorise it. At six months of age babies are more startled by, and follow visually, an object that has independent movement unrelated to any other causality. This early knowledge of animacy develops so that by the time a child is six or seven years of age it begins to realise the irreversibility of being dead and inevitability of living things dying. Alongside such developing knowledge is a developing language in which to form and express such thoughts. Tomkins and Tunnicliffe conclude that Darwin's own childhood resonates with our present knowledge about the development of biological cognition.

Fossil hunting is a popular pastime. In Chapter 12, Shirley Simon describes her own experiences of such fossil hunting and relates this to scientific enquiry, both the kind in which Darwin engaged and the kind that science teachers try to foster in school. She notes that what was special about Darwin was what he chose to observe, how he asked questions about his observations and his ability to answer these questions. Simon argues that enquiry in school science essentially includes the intentional process of diagnosing problems, critiquing experiments, distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers and forming coherent arguments. Each of these processes, she asserts, can be addressed through structured activities with students, but can present challenges for teachers who are more familiar with teaching about established scientific knowledge. Simon goes on to critique standard approaches to teaching about evolution, and suggests how science teaching can better develop enquiry and skills of argumentation.

In the final chapter in this section, Chapter 13, Peter Kennett and Chris King describe how the Earth Science Education Unit (ESEU) was formed in 1999 to provide a hands-on and interactive style of Continuing Professional Development for school science teachers and trainee (pre-service) teachers in the university sector. They go on to outline the content of a 1½ hour workshop on 'Charles Darwin, the Geologist', which they produced for the 2009 celebrations. The workshop begins with an 'icebreaker' activity that takes the form of a Darwin Quiz. Ten activities are then laid out on a 'circus' basis, where delegates are invited to carry out one or two activities only, to read the associated 'Darwin Connection' material and then to demonstrate their activity in the plenary session. A further eight activities are laid out for brief inspection and five more are described in an accompanying booklet but not displayed. The finale is a party popper 'volcanic eruption', which Kennett and King think Darwin would have loved, since he spent so much time in active seismic and volcanic regions and was well aware of their unpredictability.

CRITICAL THINKING ABOUT WHAT AND HOW WE KNOW

In Chapter 14, James Williams uses the examples from Darwin's theory of coral atoll formation (a triumph of his), his explanation of the then puzzling natural

feature of 'parallel roads' in the highland valley of Glen Roy (a rare failure of his) and his painstaking collection of facts to support his theory of evolution alongside his later work on the movement of plants to show that science and 'the scientific method', far from being one approach can be conducted in different ways, from theory building to theory confirming. Williams goes on to show how the theory of evolution is predictive, thus fulfilling one of the central features of a scientific theory. He concludes that by examining how Darwin developed and worked as a scientist and looking in detail not just at his theory of evolution but also his other work as a geologist, we can discern various aspects of working scientifically that are helpful in explaining the nature of science to students.

The theory of evolution is often said to be 'controversial'. In Chapter 15, Ralph Levinson examines what precisely is required for something to be controversial. He points out that there are different types of controversy. These differences can be summarised as follows: differences where matters can be settled one way or the other when sufficient evidence can be available; differences of priority or significance; differences through meaning of a concept or term; differences of personal, communal or social interest; differences about a whole range of fundamental value positions. Levinson goes on to consider what science teachers might do when faced with students who refuse to countenance evolution as an explanation for the diversity of life. He notes that in his experience there are two main strategies often employed: the first is to avoid active teaching of the topic altogether and remind students of relevant parts of the textbooks to read; the second is to announce that this has to be learned for the examination and avoid any discussion. Levinson considers both to be understandable responses but unsatisfactory and likens the divide between science and creationism to a hazardous border that requires careful negotiation.

As Neil Ingram notes in Chapter 16, misconceptions in understanding evolution are common. Furthermore, there are evident political and religious implications for the evolution of life through a struggle for existence. In spite of the overwhelming evidence for evolution, it remains a controversial idea for many people. Ingram reviews common misconceptions about evolution and then examines how evolution and religion intersect. He concludes that the emphasis in science teaching should be on the evidence for the processes of evolution, and that discussion of ultimate causes should be discussed elsewhere (such as in religious studies lessons).

In Chapter 17, John Taylor outlines the 'Perspectives on Science' course, a course in the history and philosophy of science for 16-18 year-old students, and then describes how Darwin's life and work provide material for one of the major historical case studies in the course. The course was designed to promote discussion and debate of historical and philosophical questions associated with science and to make such debate a recognised part of the curriculum. It is now taught in schools and colleges as a designed programme for the 'Extended Project Qualification', which offers students the opportunity to engage in research and produce university-style dissertations. The emphasis throughout the course is on encouraging students to think for themselves. Students' attention is drawn to the community of scientists

working at the same time as Darwin, such as Wallace, Cuvier, Lyell, Huxley, Hooker and Wilberforce, and to their interactions with Darwin himself. The idea of science as a social activity implies the possibility of conflict, or at least tension, and this is explored in the first activity of the evolution case study, entitled 'Darwin's dilemma'. This activity invites students to consider how they would advise Darwin to respond to the famous letter about natural selection that he received in 1858 from Alfred Russel Wallace.

Before Darwin, no botanist appreciated the significance of the insects often found on carnivorous plants. As Aaron Ellison relates in Chapter 18, it was Charles Darwin who used keen observations and literally hundreds of carefully designed experiments (Darwin, 1875) to demonstrate conclusively that these plants actively attract, trap, kill and digest insects and other small animals. Subsequent research has supported many of Darwin's conclusions about how carnivorous plants 'work' and shown how natural selection has led repeatedly to carnivory in a number of unrelated plant lineages. Ellison points out how good scientists are always trying to disprove their pet hypotheses. Scientific understanding advances most rapidly when existing explanations for observed phenomena are found wanting and new explanations are proposed and rigorously tested. The experiments described by Darwin in his work on carnivorous plants continue to provide an inspiring example of the inherent scepticism of science and of the power of such scepticism to lead to new knowledge, and a deeper understanding of the world around us.

In the summer of 1855 Charles Darwin surveyed the 13-acre hay meadow (Great Pucklands) near Down House with the help of Miss Thorley, his children's governess. As Karen James points out in Chapter 19, the survey was perhaps among the first intentional, comprehensive species counts in a geographically defined area. In an age when rare specimens were prized above all, Darwin's aim was radical: to identify all of the plant species growing on a small, unremarkable plot. During the summers of 2005, 2006 and 2007 a team from the Natural History Museum in London re-surveyed Great Pucklands meadow. The aims of the re-survey were to detect any changes in species number and diversity in the meadow since 1855, and to pilot and optimise procedures for high-throughput botany, pairing the collection and management of herbarium specimens with 'DNA barcoding', the creation of libraries of short, standardised, DNA sequences linked to representative specimens in established specimen repositories, for the eventual use in DNA-based identification of unknown samples. These aims were realised and the approach of DNA barcoding is being further developed by James and others for use with schoolchildren and other citizen scientists.

INTERDISCIPLINARY STUDIES

In the first chapter in this section, Chapter 20, Miranda Lowe and Carolyn Boulter look at Darwin's study of barnacles as an example of a Victorian scientist at work and show how students can follow in Darwin's footsteps and through that journey understand the importance of work by scientists today and see how scientific

knowledge develops. Darwin began his barnacle work simply because he was tidying up the last of the specimens collected on his *Beagle* voyage. Using his dissecting microscope he was more than a little chuffed to discover that barnacles were crustaceans not, as Linnaeus and Cuvier had presumed, molluscs. The barnacle study grew and grew. His initial delight – 'After having been so many years employed in writing my old geological observations it is delightful to use one's eyes and fingers again' – palled somewhat: 'I hate the Barnacle as no man ever did before, not even a Sailor in a slow sailing ship'. Using the narrative of how Darwin worked with barnacles can provide deep insights for students into how scientists work and the processes of taxonomy, classification and phylogeny. Lowe and Boulter describe how they have developed for the Charles Darwin Trust a unit on barnacles which is called *Darwin's barnacles: evidence for evolutionary relationships*, which allows students to work with this process.

In Chapter 21, Martin Braund shows what the Arts, particularly drama, can offer science education. Braund argues that the learner of science benefits from engagement through performance, making abstract concepts understandable as they are connected to personal experiences of mime, dance and acted drama. Engagement through drama also contributes to learners' realisation of the nature of science and appreciation of viewpoints on scientific issues, thereby enhancing their scientific literacy. Darwin's work and life inspire many examples of this learning. Simulations of survival in nature, plays about Darwin's life and ideas and role-plays about modern applications of evolution and gene selection are examples included by Braund. These inspiring moments can bring school biology and science to life. However, the biology/science teacher often needs help to make the necessary 'border crossings', bridging the pedagogy of the drama teacher to that of the science teacher.

In Chapter 22, Tina Gianquitto discusses how Darwin's work helped writers and other contemporaries of his discover new ways about talking about old topics: love and marriage, moral sense and social instincts, even aesthetic sense and the perception of beauty. Interestingly, it was Darwin's botanical books that were especially significant in this regard. Darwin's plant studies were in part so popular because he employed basic observational and experimental methods using materials close at hand. Popular nature writers, such as Mary Treat – a correspondent of Darwin's and expert on carnivorous plants – made the connection between botanical study and moral and physical health explicit. Indeed, carnivorous plants aroused a host of contradictory feelings and views. Are they conscious, wilful organisms? Are they moral, immoral or amoral? Are they examples of exquisite evolutionary adaptation or are they degenerate, atavistic throwbacks, making their way by a sort of primitive violence? Are they flora or are they fauna? Darwin's re-mapping of the natural world placed many in the nineteenth century in a profoundly disturbing position, facing a paradigm shift that necessitated an entirely new way at looking at the world and its natural systems.

Margarita Hernández-Laille, in Chapter 23, analyses the inclusion of Darwin's theory of evolution in secondary school science books in England and Spain during the

nineteenth century. In England, Darwin's ideas, even though they initially provoked controversy and criticism, were quickly introduced into school books. Indeed, the name Darwin and reference to his ideas entered English school classrooms even before the publication of *On the origin of species*, although it was not until after 1870 that the majority of school science books adopted a Darwinian approach. In Spain, the predominant position of the Catholic Church did not prevent the references to Darwinism which Spanish scientists introduced into their discourse shortly after the publication of *On the origin of species*. Nor did it take that long, albeit longer than in England, for Darwin's theory of evolution to enter the area of education in a society that was eager for modernisation. Although many teachers suffered considerable reprisals in the mid-1870s for defending science and introducing Darwinism into their classrooms, Spanish textbooks were nonetheless swift to incorporate Darwin's ideas.

DEVELOPING WORK WITH LEARNERS

In the first chapter in this section, Chapter 24, Vaughan Prain reviews Darwin's methods of enquiry and representing research, where he used writing and other forms of representation to raise and solve problems through extensive observation, written and visual records, reflection, claim-making, testing and re-representation. Prain then presents an overview of recent research on the role of writing, and more broadly representation, in learning in school science, and illustrates the implications of this research through reporting on classroom-based research on the topic of adaptation. In particular, Prain reports how his team worked with two years five and six teachers in a shared primary classroom to plan, implement and evaluate a unit on *Animals in the school environment* that included a rich range of teacher- and student-generated representational challenges, investigative activities, discussion and re-representation. Major concepts to be learnt included ecosystem, habitat, the diversity of animal populations, interactions between plants and animals in an ecosystem, animal structure and function and the adaptive purposes of behaviour. The types of drawing, the level of detail, the count of animals, the construction of a model centipede and the use of graphing all reveal how the students integrated meaning across modes, to reason about animal diversity. Teacher and peer verbal and other inputs were critical to this process.

In Chapter 25, Emma Newall explores how Darwin-inspired learning might help in the teaching of evolution by natural selection. She reports how the Charles Darwin Trust worked with a group of South London secondary schools in 2011 and 2012. A one-day workshop was developed to look at a range of Darwin-inspired topics including selective breeding, bee behaviour, climbing plants, Darwin's weed plot and intra-specific variation in plants. Some of these activities were undertaken in a classroom environment, but those involving plants were carried out in either the school grounds or a local park and the evaluations showed that being able to work

outside was considered the best bit of the day by many students. More fundamentally, the activities enabled students to see the world in a new way.

The Charles Darwin Trust has developed a number of post-16 resources and in Chapter 26, Carolyn Boulter and Emma Newall explain the thinking behind these resources. An analysis of existing advanced level biology specifications (for 16-18 year-olds) showed that there were a number of topics that teachers often regarded as difficult to teach and students often considered dull that seemed likely candidates to benefit from a Darwin-inspired approach to learning. Three modules were therefore developed: one on Darwin's birds, one on Darwin's *Drosera* and one on Darwin's barnacles. Boulter and Newall argue that too much biology education concentrates on the molecular level at the expense of whole organisms. The next generation of biologists, both specialist and generalist, requires inspiration and a broader and more holistic biological education, which they hope the modules will help to provide.

In Chapter 27, Susan Johnson discusses how school grounds can be transformed for Darwin-inspired learning. All too often schools make little or no educational use of their grounds. One problem is that teachers often lack confidence in their knowledge and understanding of the outdoor environment and teaching in school grounds. Local concerns about health and safety when working out-of-doors, curriculum pressures and other considerations can also play a part. Johnson provides a rich assortment of activities that can take place in school grounds, many directly connecting with Darwin's own work.

In Chapter 28, Susan Johnson describes how a programme of Darwin-inspired learning can facilitate the transition as students move from their primary to their secondary schools. The intention of Darwin-inspired transition days is to make full use of the outdoor environment to explore the principles underpinning Darwin's work. Even seemingly unpromising school grounds or public parks have a small, grassed area, thickets of thorny plants, weeds, trees and climbing plants. In urban school playgrounds, tiny habitats for organisms are found between paving stones, on brick walls and the weedy edges of asphalt. Understanding plant life cycles, local habitats and the wildlife that may be attracted help to illustrate Darwin's big ideas and skills as a scientist

In the final chapter of this section, Chapter 29, Dawn Sanders proposes a biographical model for using the work of scientists in teaching science. She develops two biographical narrative-based approaches to Darwin-inspired learning: one that uses Boehm's statue of Darwin in the Natural History Museum, London; one that seeks to bring Darwin to life through his personal correspondence. Darwin's overcoat, as depicted in Boehm's statue, suggests a man for whom science was not practised solely indoors, a man whose garden was part of his life and science. Sanders suggests that the many pockets of possibilities in the waistcoat, jacket and overcoat of the statue allow students to imagine their contents, as Darwin worked in the grounds at Down House and beyond. Equally, Darwin's personal correspondence, as also noted in Chapter 3, provide a rich and increasingly accessible resource with

which to appreciate Darwin's humanity, his powers of observation and the ways in which he both supports and confounds students' expectations of a great scientist.

EPILOGUE

Finally, in an epilogue the three of us summarise what is to us the essence of Darwin-inspired learning. We argue that an approach to learning inspired by Darwin can transform the ordinary, can help us to see with new eyes. Natural history is all around us but too often it is not noticed. Furthermore, a Darwinian approach to answering scientific questions shows how rich an authentic scientific approach to hypothesis formation and testing can be; too often, school learners are bored by an endless series of traditional hypothetico-deductive experimental narratives. There are common curiosities between the scientific and creative imagination. A Darwin-inspired approach to learning begins by paying attention, by close observation. Done well, school science can help develop 'everyday noticing' into 'scientific observation', the start of valid scientific investigation.

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DARWIN'S HERITAGE

RANDAL KEYNES

1. ENTERING DARWIN'S LIFE

INTRODUCTION

As a result of his fundamental contribution to human understanding, Charles Darwin touches all of our lives. I have a special connection with him as I am one of his great-great-grandchildren and a trustee of the Charles Darwin Trust, the organisation that uses the intellectual and cultural heritage of Darwin, through his approach to science and his work at Down House and in the immediate countryside, to inspire a deeper understanding of the natural world (Charles Darwin Trust, 2013).

In this chapter I begin by tracking some of Darwin's formative experiences and then connect these to what the Charles Darwin Trust understands by 'Darwin-inspired learning'.

SCHOOLBOY – EXPLORING AND EXPLOSIONS

Young Charles was 'back of the class' at school in Shrewsbury but from early childhood he loved exploring the countryside and examining plants and small creatures, collecting beetles and strange stones. His two grandfathers had both been closely involved in the wonderfully practical and adventurous experimental science of the Lunar Society in Birmingham, with Joseph Priestley a close colleague and friend. Charles's elder brother had a chemical laboratory in the tool-house and allowed Charles to assist him in making 'all the gases'. Charles helped eagerly and wrote in his autobiography that this was the best part of his education in his school years, 'for it showed me practically the meaning of experimental science' (Darwin, 1887).

In these two ways, with his exploring and collecting on his own in the countryside and then undertaking chemistry experiments with his brother in the tool-house, Charles grew into a young man 'of enlarged curiosity' as his uncle once perceptively remarked.

UNIVERSITY – FIELD TRIPS WITH EXPERTS

Finding little to interest him in his university studies, Darwin pursued his interests in natural history, studying birds and collecting beetles with student friends. Later, he criticised his earlier passion for beetle collecting, writing that he had been interested in little more about them than just 'getting them named', but he was fortunate also to find among his university lecturers and professors three outstanding naturalists

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who allowed him to accompany them on their field excursions, collect and study with them and develop his powers of observation and enquiry with their guidance. Each of them combined their expertise in field studies with bold interests in high science and global perspectives in the investigation of basic patterns of natural life. For Dr Robert Grant, the Lamarckian marine biologist in Edinburgh, it was links and distinctions between animals and plants that were of particular interest; for Professor John Henslow, the botanist in Cambridge, it was the global features of the plant kingdom; for Professor Adam Sedgwick, the geologist also in Cambridge, it was the deepest and broadest history of the earth's crust. Each of them in succession recognised the young man's absorption and fascination in what they were studying together and his potential as a scientist, and encouraged him in field-work and pursuing higher scientific enquiries.

THE *BEAGLE* VOYAGE

Henslow got Darwin onto the *Beagle* voyage as naturalist companion to the Captain. Darwin now had five years on his own as naturalist, five years of adventure exploring the world – sea and land, mountain and plain, continent and island. At that point in the history of natural science this provided an outstanding opportunity for an open-minded young investigator, and he used it well.

Darwin wrote vividly in his journal and letters home about his experiences on the voyage, especially those linked with some of the remarkable scientific insights he was developing. The importance of his observations on the Galapagos Islands is well known but he achieved much in addition. His geological and palaeontological studies changed how he saw the world. He came to see the surface of South America as pitching and heaving with geological changes – not least because of his first-hand experience of an earthquake in Chile – and he found patterns of succession between the extinct and living mammals of the Continent that Owen later made his 'law of succession', a key point for *On the origin of species*. His theory of the formation of coral reefs enabled him to trace global patterns of uplift and sinking, all hypothesised inductively and confirmed by careful observation as the *Beagle* sailed from archipelago to archipelago around the Pacific.

LONDON AND SPECIES THEORY

Back in London in 1836 Darwin lived and worked in the teeming, smoking city for six years. He delivered his many *Beagle* specimens to museum experts for identification and got their judgements on the Galapagos mockingbirds and finches he had collected. Gradually, he came to see the implications of his work for the 'species question' in taxonomy, a hot topic in natural science, and for what Sir John Herschel referred to in a letter to Charles Lyell as 'the mystery of mysteries, the replacement of extinct species by others'. Darwin started thinking hard about species and variation, the how and the why, and focused on possible processes for change.

As he read widely, Thomas Malthus' (1798) *An essay on the principle of population* alerted him to the importance of competition in nature. Eager to prove himself as a scientist, Darwin considered change with patterns in space (mockingbirds from Uruguay to Peru and then the Galapagos Islands), through time (fossil and living mammals in South America) and in taxonomy and embryology (comparative anatomy), and put together a first outline for a whole theory of natural life based on species change, his '1842 sketch'. He realised it would be rejected out of hand by almost all respectable scientists, and saw he would need to develop many parts of it in secret and test each rigorously against all the evidence he could find before he could offer it to the scientific community. Darwin's big ideas developed from his *Beagle* experiences and he drew on London's museums and libraries. Part of his genius was his ability to see the connections among a huge range of apparently disparate facts, enabling him to explain many things in widely different fields, each inexplicable in isolation but all making sense when seen together in his suggested framework. He saw at once in each topic many questions he'd like to put to many different people, and many experiments he'd like to try to see if they might provide any insights, but he couldn't do as much as he wanted while he was working and living in London, so he opened a book for all the points he wanted to pursue, scrawling simply on the cover, 'Questions and Experiments'.

Darwin's secret notebooks of 1836 to 1844, in which he noted his developing ideas in rapid, incisive comments, provide an outstandingly vivid display of one of the fastest and greatest achievements in scientific thinking. His historic jotting after first visiting Jenny, a young orangutan in the Zoological Gardens, to see how like or different from a human she might be, shows the breath-taking openness of his mind and boldness of his thinking: 'Man in his arrogance thinks himself a great work, worthy the interposition of a deity [i.e. specially created by God]. More humble and I believe true to consider him created from animals'.

DOWNE[1] – A PLACE TO WORK

When Darwin had written out the 1842 sketch, he could see that his idea might stand up and he decided to make it his life's work. To develop it he realised he'd need peace and quiet from social calls, and a garden and countryside to observe and experiment in, but he'd also have to be able to get to London easily to read books, examine museum specimens and consult experts. He decided with Emma, his wife, to move into the country. They found a small country house in a quiet part of Kent and moved there in September 1842 with their two young children. The couple were to live there, at Down House near Downe, for the rest of their lives, and Darwin made it his single workplace from then on. Darwin and Emma had looked at many properties in all directions out of London, and one important reason for their final choice of Downe was the variety of habitats he could find in that quiet neighbourhood, which he could explore, observe and collect in using the network of footpaths in every direction.