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**Abstract**
Currently there are moves to increase learning out-of-doors and to represent the work of inspirational scientists in the secondary science curriculum. In 2009 the scientific processes and knowledge derived from Darwin's work, much of which was undertaken out-of-doors, will feature prominently in science education. His simple, hands-on, practical enquiries can be replicated in schools. Here his weed plot and worm cast experiments are described and their implications discussed.

## Teaching Science out-of-doors

Education policy is shifting science teaching. The EU commission (2007) wants school science to be based on enquiry and reasoning. UK government initiatives like the *Learning Outside the Classroom Manifesto* (DfES, 2006) are expecting integration of outdoor education into the curriculum.

Equally important are active debates about curriculum, processes of critical reasoning and argumentation in school science (Driver, Leach, Millar, & Scott, 1996; Driver, Newton, & Osborne, 2000; Millar & Osborne, 1998), because science education has been more concerned with students' understanding of scientific concepts. Implementing investigations out-of-doors has holistic teaching potential; learning is presented as hands-on activity and students encounter a different learning style (Johnson 2004).

Rees (2007) notes a worrying absence of references to Darwin in current A-level Biology specifications and some texts. Equally regrettable is the often fragmented knowledge of ecology that can reduce a teacher's confidence to use creative pedagogy (Harlen, 1999). The Association for Science Education (ASE) and Field Studies Council (FSC) (Tilling & Dillon, 2007) hope changes in policy will support early career training and CPD for science teachers. New teaching activities and strategies must enrich science and learning goals to enable expansion outwards from conceptual understanding. If teachers join students in observing evidence out-of-doors and co-construction of knowledge, using reasoning and social skills, they will be modelling methodology Darwin used.

### Darwin related science and how to teach it

Support may come in 2009 in the form of activities planned to celebrate the bicentenary of Charles Darwin's birth and 150 years since the publication of *On the*

*Origin of Species* (1859). Although the young Darwin was neither especially observant nor meticulous in later life he worked meticulously e.g. dissecting thousands of barnacles and engaged with expert practitioners including gardeners and livestock producers to develop his theories. He is a model for inductive reasoning and ways of validating research.

Teachers' own knowledge and experiences influence their confidence to teach a subject (Boud et al, 1985; McNamara, 1994; TDA, 2007) and in 2009 perspective change is unlikely to come without copious input. There are many readable and fascinating insights to inspire lessons in Darwin's best known work, *On the Origin of Species*, available online at www.darwin-online.org.uk. So too are his other books on specific organisms e.g. climbing plants, insectivorous plants, cross and self fertilisation, different forms of flowers, the power of movement in plants, fertilisation of orchids and worms that produced the "vegetable mould" (soil) he investigated. He also studied behaviour in animals and humans e.g. variation under domestication, sexual selection in humans or expression of the emotions. They all confirm that, simultaneously, Darwin developed knowledge and the processes of investigation; what in education jargon are subject knowledge and learning skills.

Darwin also discussed his ideas, with notable scientist of the day; Charles Lyell the geologist, Thomas Huxley the zoologist, botanists Asa Gray and Joseph D. Hooker, and the naturalist Alfred Russel Wallace who all challenged his ideas and made him review his work. Details of some 14,500 letters are online at http://www.darwinproject.ac.uk/. In them we see not only his life and time but we can assess how his thinking developed and how he collaborated, and co-constructed knowledge, with his peers.

Aspects of Darwin's methodology are being elaborated for teachers by the Charles Darwin Forum and are discussed by Boulter and Keynes (2008).

**Examples of what can be taught – when and how?**

Currently, Darwin related science in secondary schools is taught according to National Curriculum Key stage subject content and uses scientific methodology expected at that level (Grace, Hanley and Johnson, 2008). In this framework and processed through schemes of work, Darwin's scientific ideas are compressed, and his methodology is subsumed into the narrow teaching of ideas and evidence or are unrecognisable in the broad spectrum of, what is now, standard practice. The argument persists that there is insufficient time to deviate significantly from set schemes of work and the unit tests that follow.

Pressurised teaching and learning masks the interconnectedness of "subject domains" (Johnson, 2004). Equally, the outdated separation of informal and formal learning obscures a continuum of experience and enquiry in which Darwin worked towards his scientific understanding. He connected letters, articles, conversations with experts, results of experiments relevant to many “subjects” and applied them to observation spanning 40 years either in his study, his garden, at livestock shows or on his walks in Kentish lanes.

Present-day outdoor experimentation in secondary schools in no way reflects Darwin’s example. Primary schools education out-of-doors provides a modest base from which the secondary phase descends. Teachers cite time pressures, poor school grounds, management of classes out-of-doors, Health & Safety regulations or the cost of visiting relevant sites (Foskett, 2001; Johnson 2004).

Without a depth and breadth of knowledge, discussion of genetics and other socio-scientific ideas are abbreviated and Intelligent design or Creationism seem acceptable, especially when raised in other subjects where a teacher’s scientific background is inadequate when answering students’ questions (Jones & Reiss, 2007).

**Darwin experiments**

Proposed for his bicentenary in 2009 is promotion of experiments Darwin used in his work. The Charles Darwin Trust carried out research over the past 3 years into Darwin’s ways of working and introduced simple experiments in pilot Continuing Professional Development (CPD) for secondary teachers at Down House and Science Learning Centre London. Because Darwin liked to build understanding from common knowledge and experience rather than obscure or abstract sources, these simple experiments, set up in his garden, can be replicated in school grounds.

**The weed garden experiment**

Photograph A recreation of the weed patch experiment at Down House.

Darwin carried out his 'Weed Garden' experiment at Down House from January to August 1857. He was investigating the struggle for existence relevant to his theory of evolution by natural selection which appeared in 1859 as *On the Origin of Species*.

Darwin saw the struggle for existence as ruthless, universal and ceaselessly shifting. He wanted to understand how natural selection worked to drive evolution through the life cycles of every organism. Changes take place from day to night, from season to season, through the stages of each life cycle and different forces intrude at different times for each organism. If we observe individual species of birds or insects we may not realise the struggle for existence that is going on or their dependence on each other "in so complex a manner" (Darwin, 1859). We need to recognise it and use the distinctive way Darwin found to detect and show what is happening.

Darwin isolated a group of organisms (plants) at the seedling stage, free from the pressure of crowding by other plants but still subject to the cumulative effects of other destructive forces. He identified or guessed these forces e.g. insects, slugs, worms, rain and drought, and noted them. Then he observed how many plants were destroyed and looked at each destructive force equally.

Darwin cleared a patch of poor soil of all perennial weeds in January (we think he meant both above and below ground). He erected a barrier to protect it "from large animals". Then he watched for seedlings to emerge.

Seedlings began to appear in early March. He visited the plot daily and marked each seedling with a wire (10cm long garden wire). He noted activities by slugs, worms and insects, and weather conditions e.g. heavy rain or drought, that might explain loss or survival of seedlings.

On 31st March, 10th April, 20th April, 8th May, 1st June, 1st July and 1st August, he counted the wires without a seedling because that seedling had been destroyed. He removed the wire. He recorded numbers lost and surviving and notes about climate or other factors that might explain the losses. 357 seedlings emerged but only 17% survived until August.

**Practical action in school**

To replicate Darwin's experiment, choose a plot of poor soil 90cm x 60cm in January. Follow his experiment as set out. On or about the dates mentioned and the end of term instead of 1st August: count markers (equivalent of Darwin's wires) without a seedling and record this number because it indicates that seedlings have been destroyed; remove those markers. At the end of the summer term identify and record the surviving plants.

**Analysis**

Data can be compared with Darwin's results for 1857 and the results of 2005. The first figure in each group of three is the number of seedlings killed since the previous count. The second figure is the number of surviving seedlings. The third figure is the total number of seedlings that have emerged and survived or been killed to date.

| ***Dead/surviving/total on*** | ***1857*** | ***2005*** |
|---|---|---|
| 31 March | 25/30/55 | 20/160/180 |
| | | |
| 10 April | 84/ | 22/243/265 |
| | | |
| 20 April | 112/ | 54/242/296 |
| | | |
| 8 May | 197/ | 67/346/413 |
| | | |
| 1 June | 277/80/357 | 94/403/497 |
| | | |
| 1 July | 290/67/357 | 155/384/539 |
| | | |
| 1 August | 295/62/357 | 199/340/539 |

(Weather and other information can be provided for 1857, to enable comparison.) Discuss the findings. Consider all factors that may explain the differences between Darwin's results in 1857 those for 2005 and your results e.g. seeds in the soil and recent history of the cleared patch; the kinds and numbers of pests in 1857, before insecticide use, and now; the weather now and in 1857 and 2005 affecting germination, growth and pest activity.

Extension activity: Consider survival time and rate of survival of different plants that can be identified e.g. were they annual/perennial, shallow/deep-rooted, the life cycles of the pests that attack them. Identify adaptations in relation to these observations.

**Worm cast experiment**

Photograph of worm casts.

An experiment that could be completed by feeder or cluster schools explores the behaviour of earthworms. Health and Safety issues regarding soil handing can be found via http://www.soil-net.com/ (washing hands after activities is important) and it may also be helpful to use the Field Studies Council *Aidgap* guide (Trudgill, 1989) when investigating soil acidity, soil composition and variations in soil profiles.

In March or October select 5, 1 metre squares; one in a flat, grass-covered area and others in different environments e.g. poor soil, under a tree, on a slope. Dig a hole the same size close to each plot to check the soil composition beneath the surface. Erect a barrier around both of these plots. Identify and note plants on the plots and nearby. Check whether the plots are shaded during the day.

Before any worm casts are collected remove existing ones carefully and mow and/or sweep the plot which is flat and grass covered. Collect worm casts from the plots on the next 5 school days. Note the weather conditions on each day. Weigh the worm casts after they have been dried. Compare the results for different locations.

Darwin repeated this experiment in many locations, unenclosed common land, “at a height of about 700 ft.” above sea level on short, fine turf; on red clay full of flints overlying chalk; poor pasture land at the bottom of a valley; a sloping surface on his lawn; near the sea, a lawn protected by shrubberies; on sandy soil and on chalky soil.

He found not only the weight of soil that had been brought to the surface but, by simple multiplication, the result for an acre of land [substitute a hectare] and how much sub-soil might be ejected in a year.

Extension activity: Darwin discovered when worms do not work. Compare the findings from the school plot over a period of time with Darwin’s conclusions (Darwin, 1881).

**Implications**

It is important that Darwin experiments include an out-of-doors element because he always thought about continually active natural processes happening all around him, whether experimenting on the Beagle voyage, at Down House, in the countryside around Downe village or as he observed daily and seasonal changes as he walked around his Sandwalk. Currently, this link between observations out-of-doors and scientific understanding is absent.

Full knowledge does not comes in "discrete puzzle pieces" (Bell & Gilbert, 1996) that fit together to complete a picture. Darwin’s experiments demonstrate this concept as each inference from an experiment or observation added to or changed his thinking; the tentative nature of science was evident. Students need opportunities to relate to a small patch of the earth to show that science is tentative and connected to everyday existence.

Experiments designed to engage students and increase the probability of learning can be simple but planning is needed to include cross-curricular links and use of new technology e.g. mobile phone to record evidence out of doors (Johnson, 2007). Implementation of science enquiry skills, integration of knowledge, argumentation and decision making are incorporated in an inclusive environment if lessons out-of-doors are well coordinated and resourced.

Assistance with the background to these experiments or CPD is available from The Charles Darwin Trust and London Science Learning centre. Organisations that provide opportunities to engage with Darwin experiments in 2009 are the Royal Horticultural Society, Wakehurst Place and other botanic gardens. The Wellcome Trust intends to engage as many schools as possible in one or more Darwin experiments in 2009. The Darwin bicentenary website www.Darwin200.org/ has details of contributors to and events in 2009.

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