

I do believe in taking seriously and respectfully the concerns of students who do not accept the theory of evolution, while still introducing them to it. While it is unlikely that this will help students who have a conflict between science and their religious beliefs to resolve the conflict, good science teaching can help students to manage it – and to learn more science. Creationism can profitably be seen not as a simple misconception that careful science teaching can correct, as careful science teaching might hope to persuade a student that an object continues at uniform velocity unless acted on by a net force, or that most of the mass of a plant comes from air. Rather, a student who believes in creationism can be seen as inhabiting a non-scientific worldview.

References

- Barbour, I. G. (1990) *Religion in an age of science: The Gifford Lectures 1989–1991*. Vol. 1. London: SCM.
- Brooke, J. H. (1991) *Science and religion: some historical perspectives*. Cambridge: Cambridge University Press.
- Cobern, W. W. (1996) Worldview theory and conceptual change in science education. *Science Education*, **80**, 579–610.
- Colburn, A. and Henriques, L. (2006) Clergy views on evolution, creationism, science, and religion. *Journal of Research in Science Teaching*, **43**, 419–442.
- Dawkins, R. (2006) *The God delusion*. London: Bantam Press.
- DCSF (2007) *Guidance on creationism and intelligent design*. Available at: www.teachernet.gov.uk/docbank/index.cfm?id=11890 (accessed 12 January 2008).
- Jones, L. and Reiss, M. J. ed. (2007) *Teaching about scientific origins: taking account of creationism*. New York: Peter Lang.
- Kitcher, P. (1982) *Abusing science: the case against creationism*. Milton Keynes: Open University Press.
- McCrath, A. (2005) *Dawkins' God: genes, memes, and the meaning of life*. Oxford: Blackwell.
- National Academy of Sciences and Institute of Medicine (2008) *Science, evolution, and creationism*. Washington DC: National Academies Press.
- Reiss, M. J. (in press) Imagining the world: the significance of religious worldviews for science education. *Science & Education*.
- Roszak, T. (1994) God and the final frontier. *New Scientist*, 28 March, 40–41.
- Scott, E. (1999) The creation/evolution continuum. *Reports of the National Center for Science Education*, **19**, 16–23.
- Smart, N. (1998) *The world's religions*. 2nd edn. Cambridge: Cambridge University Press.

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Teaching evolutionary biology in schools to foster active learning

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ABSTRACT Does school biology education adequately prepare students for further learning in science, both at university and in a wider social context? Students beginning a university-level course in biology often face several obstacles. Firstly, they need to develop skills needed for independent study and critical thinking. Secondly, university biology courses are increasingly being structured around an understanding of evolutionary biology, yet studies show students who have studied biology at school level often have a relatively poor grasp of evolutionary principles. By teaching evolutionary biology in an enquiry-led approach in schools, students can gain a better understanding of biology, and also develop a greater appreciation of science as a process of testing claims about the world. In this article I discuss my experiences teaching evolutionary biology to entry-level university students, and briefly describe some of the ways in which I used simple online-learning activities to encourage active learning, engage independent study skills and foster critical thinking.

Encouraging active learning in biology students

One of the complaints frequently heard in university staff rooms is that 'these days students expect to be spoon-fed'. Academics feel frustrated when their students expect to be given a list of facts that need to be reproduced faithfully on exam papers. In an ideal world, they would want their students to be motivated enough to ask questions for themselves, skilled in seeking answers to those questions, and smart enough to weigh up competing ideas in order to make up their own minds. These abilities are important in all fields of study and to life-long learning outside the formal education system, and will be fostered by any good educational programme at any level of learning. But active learning and critical-thinking skills have not always been promoted in school biology classes. Biology is sometimes taught as if students should be passive absorbers of a large body of facts about the world, rewarding the faithful reproduction of these facts for assessment items. While there is merit in learning basic biological knowledge, the passive learning approach does not equip students for future

learning. This is particularly important in the rapidly changing field of biology, where the 'facts' should not just learn existing knowledge, but also be able to evaluate and incorporate new data and changing ideas. If we wish to produce good biologists, and scientifically literate members of society, the best we can do is give them the ability to keep up with new developments. To be scientifically literate means more than knowing of the terminology: it requires an understanding of science as a process (Alters and Nelson, 2002) and the ability to evaluate competing explanations (Gross, 2006).

Nowhere in biology education is an emphasis on enquiry, rather than fact-retention, more critical than in the field of evolutionary biology, for two reasons. Firstly, evolutionary biology is a dynamic and growing field of research, which means that there is constant generation and testing of new ideas. For many key ideas in evolutionary biology, there are several alternative hypotheses that are the subject of ongoing research and, as new facts come to light or new tests are devised, the weight of opinion may shift in favour of particular ideas. Therefore, it is impossible to

produce a static catalogue of facts that constitute current knowledge about evolution. Secondly, studies have shown that an enquiry-led approach to learning about evolution (where students are given the time and resources to compare alternative hypotheses) is more successful than a transmission-based approach (where students are taught a set of facts) (Woods, 2001; Alters and Nelson, 2002; Marrs and Novak, 2004; Robbins and Roy, 2007). While this makes evolutionary biology challenging to teach to high school students, the potential benefits are huge. Studies often reveal that school students have a relatively poor understanding of how to apply evolutionary thinking to problems in biology (e.g. Alters and Nelson, 2002; Tidon and Lewontin, 2004; Robbins and Roy, 2007). Enquiry-based teaching of evolution will not only improve students' understanding of the central themes of biology, but also the nature of science itself: *teaching about evolution affords an important opportunity to science teachers to teach about key aspects of scientific enquiry*' (Crawford *et al.*, 2005).

Enquiry-based learning can also help science students prepare for the challenging transition from school to university. Even students who have performed academically very well at school will find that they need to develop a range of new learning skills in order to survive and thrive as they make the transition from small-group teaching in schools to predominantly large-group teaching in most university science courses.

Moving from being in a class of 30 or so high school students to participating in a lecture-based course with hundreds of other students has profound implications for learning style. Instead of face-to-face contact with teachers, the student has a more distant relationship to their lecturer (to the extent that they may never speak to them directly), so the opportunity for discussion-based learning may be limited. Instead, the predominant mode of teaching in many university science courses is transmission-based: as a lecturer talks, the students write notes to record the content of the lecture, which they use as a guide to what they are expected to know to succeed in the course.

Because of the emphasis on large-group teaching, several challenges typically arise for school students beginning a science degree. In transmission-based tuition, there may be little opportunity for students to direct the pace of

learning, or to clarify difficult points. Instead, the student is expected to learn new material and ideas at the pace dictated by the lecturer. In addition, limits to staff time may necessitate few large assessment items, rather than continuous feedback, so students may find it difficult to judge their progress. So, in a course of hundreds of students, it is possible for an individual student to fall behind without any member of staff noticing, or having the time or resources to help that student catch up. Furthermore, unlike in high school, at university most of the teaching is done by staff chosen for their research skills; very few have any formal training in teaching. While many university lecturers are excellent teachers, some are less than perfect at communicating with students, compounding the difficulties associated with the transition to university education. In summary, one of the greatest challenges for students starting university is to become active, independent learners, able to judge what they need to know, what they need to do to improve their understanding, and with the self-discipline to set a study schedule that allows them to keep up with the syllabus and meet all the assessment requirements.

Using online activities to promote active learning

Critical-thinking skills are essential to understanding evolution, and the best way to improve critical-thinking skills is to involve students in active exploration and discussion of a topic. There is a strong link between effective learning and students' active involvement in their learning: students learning by active engagement outperform students taught by transmission of information (Alters and Nelson, 2002; Marrs and Novak, 2004). Small-group teaching – involving active discussions between students and their teachers and peers – is one of the most effective ways to encourage active learning, but resources do not always permit increases in small-group work, and it may be less successful for students who do not like engaging in discussion, or struggle to keep up with group conversations. Online activities can help bring the benefits of active engagement without relying on participation in class discussion.

One of the major advantages of internet activities is that they can be designed so that

the student completes them in their own time at their own pace, spending more time on issues that they don't understand (Crawford *et al.*, 2005). Online resources can also focus students' minds on particular questions, to promote active engagement with the material covered in the course (Alters and Nelson, 2002). Asking open questions online allows students to examine their own understanding in a non-threatening environment, and can prompt students to take the initiative to do further reading, rather than focusing only on facts to reproduce on an exam paper (Marrs and Novak, 2004).

Online activities can also get students into the habit of taking charge of their own learning, building on skills most students have (Internet searching) to develop useful study habits (researching different ideas, weighing up support for different hypotheses – see Marrs and Novak, 2004; Gross, 2006). The encouragement to undertake further reading on topics, and then form their own opinions, empowers students to take 'ownership' of material learned, rather than be passive vessels for information. Students with ownership of the material learn better and ask questions about a topic (Woods and Scharmann, 2001). Online material can also add immediacy and relevance to subjects covered by linking to current news events, or incorporating and responding to student comments (Marrs and Novak, 2004). Electronic resources put real data and methods, and many primary scientific sources, within reach of students and teachers at high school (Terry, 2004; Crawford *et al.*, 2005). Indeed, the Internet is now an integral part of biological research, so should be included in a broad biological curriculum.

Feedback and frequent assessment are keys to learning effectively, to allow students to make adjustments to their own understanding and to adapt ways of learning to the requirements of the course. Students perform best when they have regular feedback on whether they have understood course material, which allows opportunity for correcting misconceptions (Marrs and Novak, 2004). But, given that teachers are commonly stretched to the limit, increase in the frequency of assessment cannot be at the expense of more staff time spent marking. Self-assessment is a surprisingly effective solution to this problem. Online self-assessment activities allow students to

judge their own progress without having to do so in front of their peers or teachers. Multiple-choice questions can be designed to test understanding rather than memory (Alters and Nelson, 2002), giving students continuous feedback on their understanding of course material without requiring extra staff marking time. Having asynchronous Internet-based self-assessment that does not contribute to formal assessment puts the responsibility on the student: they can easily cheat, but they will gain little from doing so. The following case study shows that biology students beginning university can seize the opportunity for voluntary online lessons and self-assessment and that it improves their performance in an introductory evolutionary biology course.

Case study: teaching evolutionary biology to entry-level university students

For several years I taught an introductory biology course at the University of Sussex in the UK. At Sussex, evolutionary biology was considered to be the core subject in biological education, so all biology students took one or two terms of evolutionary biology in their first year at university. My course, which was included in a dozen or more different degree programmes ranging from neuroscience to environmental studies, had a typical enrolment of around one hundred students from a wide variety of educational backgrounds. Some of these students had studied biology at school, but some were studying biology for the first time at university.

The course was based around a selection of 'episodes' in the history of life, each of which was used to explore basic evolutionary principles and ways of conducting research in evolutionary biology. For example, a lecture on the origin of life gave the opportunity to test the students' understanding of natural selection by applying it to chemical self-replication, and allowed exploration of the interplay between theoretical models and laboratory experiments. A lecture on dinosaur extinctions examined the role of major events in shaping Earth history, and explored alternative hypotheses for dinosaur mass extinction (meteorite impact, volcanism, competition with mammals, etc.) by asking what predictions each hypothesis made, and then comparing those predictions to observations from geology, palaeontology, biogeography,

systematics and so on. At the end of each lecture, I summarised the support for each alternative hypothesis and encouraged students to form their own opinion about which one they thought had the best explanatory power.

While some students found the hypothesis-based approach exciting and engaging, other students found this approach challenging and frustrating. A common response was 'just tell us the right answer'. But I don't know which hypothesis is right, and even if I have a personal opinion about which hypothesis is more plausible, it would be dishonest of me to pretend the issue is resolved. However, the critical-thinking skills needed to evaluate hypotheses and generate informed opinions are not inbuilt in all students. We need to teach these skills, just as we teach other skills associated with biology, such as statistical analysis or sampling strategies. Because it is difficult to develop these skills in large-group teaching, and we did not have the resources to increase the amount of small-group tutorials in the course, I developed a number of simple Internet-based learning tools to help students become accustomed to evaluating hypotheses, and to foster independent study skills (Bromham and Oprandi, 2006).

I developed a series of online lessons for my course that supplemented rather than reiterated face-to-face classes: some (but not all) of the key points raised in lectures were re-emphasised, but additional material was presented and novel questions raised. Online lessons were provided in the form of 'walk through' information, where each point was read before clicking to get to the next point. The online lessons included open-ended questions arising from the material, and an annotated list of links to online resources, to encourage students to think beyond the information presented and form an opinion based on what they had read. At the end of each lesson, students could choose to undertake a self-assessment task of two multiple-choice questions, with immediate feedback.

Neither the online lesson nor the self-assessment activities were compulsory, yet, on average, over two-thirds of the students voluntarily completed each online lesson and self-assessment exercise. But when the same information was presented as a 'flat' non-interactive website without self-assessment,

significantly fewer students accessed the online material. Interactive websites that supplemented class activities – providing new material as well as reinforcing some key points – were more successful than online provision of lecture notes that repeated exactly the material covered in the lecture (even though students said that they preferred the lecture-note format, fewer of them accessed online information when it was provided in this form) (Bromham and Oprandi 2006).

Students did not need constant reminders to undertake online activities, but online access rates were much higher following face-to-face classes. Performance in the self-assessment exercises was a significant predictor of performance in formal assessment, and student performance in the course increased with the number of self-assessment activities the student undertook. From a more qualitative perspective, there was a marked increase in student confidence and independence when online material was presented as an interactive website with self-assessment than when the same information was presented in a non-interactive format. The practical benefits of this increased independence were that students performed better in formal assessments, and they relied less on staff to direct their study.

Teaching evolutionary biology can foster critical-thinking skills

Evolutionary biology, like any dynamic area of science, is constantly changing. In order to be truly biologically literate, students not only need to understand evolutionary principles and be able to apply them to new information and novel situations, they need the skills to be able to seek out and incorporate new ideas and to weigh up alternative explanations. Both of these core requirements can be achieved through teaching evolutionary biology in schools in an enquiry-based approach and by giving students the support they need to develop the skills for independent learning and critical thinking. But critical thinking is not an easy skill to teach. Science students, in particular, are sometimes prone to regard education as the acquisition of objective facts and may be resistant to a more subjective approach in which they are encouraged to develop and defend personal opinions. We need to teach our school students that being able to ask good questions is as critical to success in science as finding out the

right answers.

There is a large body of literature on teaching evolutionary biology, and a growing body of excellent online resources to help teachers (e.g. Working Group on Teaching Evolution, 1998; Cracraft and Bybee, 2004; Terry, 2004; University of California Museum of Paleontology) and this is not the place to summarise it. One possible starting point for an enquiry-led approach to evolutionary biology is to focus on a historical case study as an illustration of how key scientific questions arose and how they were answered. This illustrates the dynamic nature of science through time, and prompts students to think about alternative explanations for a phenomenon and to understand the role of predictions, tests and observation in evaluating alternative explanations (Alters and Nelson, 2002; Farber, 2003; Terry, 2004). For example, contrasting the catastrophist views of Earth history championed by the great French naturalist Georges Cuvier with the gradualist explanations favoured by the English geologist Charles Lyell (and, following in Lyell's footsteps, by Charles Darwin), helps students understand the nature of the fossil record and how palaeontological knowledge has improved over time, as well as providing a deeper understanding of why Darwin advocated gradual accumulation of evolutionary change. These historical debates can be contrasted to modern discussions about the nature and causes of mass extinctions. The same approach can be extended to current areas of debate, such as the debate over whether the Pleistocene megafauna (such as mammoths and giant wombats) were driven to extinction by human hunting, anthropogenic habitat modification, climate change or a combination of all three. In particular, a hypothesis-driven approach to learning evolutionary biology should emphasise the diversity of ways of undertaking scientific research (Farber, 2003).

Some school teachers are reluctant to teach evolutionary biology because they feel uncomfortable teaching a subject they regard as 'controversial' (BBC News, 2007). But an important message of the enquiry-led approach is that lack of agreement within a scientific field does not weaken attempts to teach the subject (Farber, 2003). Instead it will enrich students' understanding of the way that science progresses, and how science differs from other fields of

enquiry. For example, students are often familiar with an adversarial model of debate – pro versus anti – that may provide a useful model for understanding the legal or parliamentary system, but can be counterproductive for exploring the nature of scientific enquiry (Scharmann, 2004). This misunderstanding of the nature of scientific debate can be seen in the response to news items where a scientist (or, often, a non-scientist) makes a controversial claim that is refuted by the 'mainstream' scientific community. Both the renegade and mainstream opinions are given equal weight, and many readers form the opinion that there is a serious challenge to orthodoxy and that mainstream professionals are trying to stifle alternative views.

There are many examples of such conflicts. For example, perceived scientific disagreements about vaccination, spread and magnified by the media, can cause a dangerous drop in public confidence (Petts and Niemeyer, 2004). A single paper published in 1998 presented no evidence for a link between the measles–mumps–rubella (MMR) vaccination and the incidence of autism but suggested that the hypothetical link could be investigated in the future (Wakefield *et al.*, 1998). This suggestion was falsely reported in the media as casting doubt on the safety of the vaccine, creating a public controversy and loss of confidence in the MMR vaccine. The subsequent drop in vaccination rates was followed by an increase in outbreaks of measles (Jansen *et al.*, 2003). Research suggests that most people passively absorbed media-presented ideas about risks associated with the MMR vaccine and did not know how to access reliable information on the topic (Petts and Niemeyer, 2004). Similarly, the world campaign for the eradication of polio suffered a setback when rumours about vaccine safety started an anti-vaccination movement in Nigeria, which resulted in outbreaks of polio which then spread around the world (Jegede, 2007).

Scientific literacy is needed to help people judge the veracity of important claims such as those made about vaccination safety. But true scientific literacy is not simply an understanding of the terms and concepts involved: it requires an understanding of the process of science. It seems obvious to working scientists that the unsupported claims of a fringe group should carry little weight,

but scientists are, on the whole, accustomed to the fact that not all scientists agree. But this is not the image of science that is commonly portrayed in the popular press and, to some extent, in textbooks, where science is presented as a body of agreed knowledge. Thus many people equate scientific dissent as serious cause for doubt. This is nowhere more obvious than in evolutionary biology where a vocal minority (from outside the biological research community) suggest that incomplete knowledge of evolution is equivalent to doubt that evolution occurs at all (Scott and Branch, 2003; Langen, 2004). An understanding of the nature of science is needed to demonstrate to school students that debate within scientific circles concerns the way that evolution occurs. Misinterpretation of debates in evolutionary biology might be less of a problem if students were accustomed to thinking of science as a process of hypothesis testing.

Conclusions

Teaching science in schools as a system of testing claims about the world rather than a catalogue of facts empowers students to take ownership of learning, rather than to behave as passive receptacles into which facts are poured. It also gives them a future-proof education. We cannot guarantee that the things we teach biology students today will not be revised or disproved in years to come. But, if we teach them the independent-study skills they need to engage with new ideas, and the critical-thinking skills they need to evaluate hypotheses, then we give them the tools for lifelong learning. In the case of evolutionary biology, students gain a deeper understanding of evolution by learning in a hypothesis-testing approach than they do by fact-acquisition approaches, and it presents a more accurate and exciting view of a dynamic field of scientific research. Teaching school students about biology as a process rather than as a static body of facts would also make students less vulnerable to being swayed by minority voices that claim that 'unknown' equals 'unknowable', or that debate is the sign of a science in trouble. On the contrary, it is the sign of a healthy and vibrant field of research.

References

- Alters, B. J. and Nelson, C. E. (2002) Teaching evolution in higher education. *Evolution*, **56**, 1891–1901.
- BBC News (2007) *Teachers' year evolution lessons*. 4 October http://news.bbc.co.uk/1/hi/6817/2/hi/uk_news/education/7028639.stm
- Bromham, L. and Oprandi, P. (2006) Evolution online: using a virtual learning environment to develop active learning in undergraduates. *Journal of Biological Education*, **41**, 21–25.
- Cracraft, J. and Bybee, R. ed. (2004) *Evolutionary science and society: educating a new generation*. American Institute of Biological Science. Available at: <http://ibses.org/curriculumdevelopment/highschool/evolution/pdf.html>
- Crawford, B. A., Zembal-Saul, C., Munford, D. and Friedrichsen, P. (2005) Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching*, **42**, 613–637.
- Farber, P. (2003) Teaching evolution and the nature of science. *The American Biology Teacher*, **65**, 347–354.
- Gross, L. (2006) Scientific illiteracy and the partisan takeover of biology. *PLoS Biology*, **4**, e167.
- Janssen, V. A. A. et al. (2003) Measles outbreaks in a population with declining vaccine uptake. *Science*, **301**, 804.
- Jegede, A. S. (2007) What led to the Nigerian boycott of the polio vaccination campaign? *PLoS Medicine*, **4**, e73.
- Langen, T. A. (2004) What's right with 'teaching the controversy'? *Trends in Ecology and Evolution*, **19**, 114–115.
- Marrs, K. A. and Novak, G. (2004) Just-in-time teaching in biology: creating an active learner classroom using the Internet. *Cell Biology Education*, **3**, 49–61.
- Petts, J. and Niemeyer, S. (2004) Health risk communication and amplification: learning from the MMR vaccination controversy. *Health, Risk and Society*, **6**, 7–23.
- Robbins, J. R. and Roy, P. (2007) The natural selection: identifying and correcting non-science student preconceptions through an inquiry-based, critical approach to evolution. *The American Biology Teacher*, **69**, 460.
- Scharmann, L. C. (2004) The instructional role of scientific theory. In *Evolutionary science and society: educating a new generation*, ed. Cracraft, J. and Bybee, R. American Institute of Biological Science.

- Scott, E. C. and Branch, G. (2003) Evolution: what's wrong with 'teaching the controversy'? *Trends in Ecology and Evolution*, **18**, 499–502.
- Terry, M. (2004) Tending the tree of life in the high school garden. In *Evolutionary science and society: educating a new generation*, ed. Cracraft, J. and Bybee, R. American Institute of Biological Science.
- Tidon, R. and Lewontin, R. C. (2004) Teaching evolutionary biology. *Genetics and Molecular Biology*, **27**, 124–131.
- Wakefield, A. J., Murch, S. H., Anthony, A., Linne, J., Casson, D. M. and Malik, M., et al. (1998) Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive development disorder in children. *The Lancet*, **351**, 637–641.

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