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Dealing with creationist challenges. What European biology teachers might expect in the classroom

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Creationists are becoming more active in Europe. We expect that European biology teachers will be more frequently challenged by students who introduce creationist misconceptions of evolutionary theory into the classroom. Moreover, research suggests that not all teachers are equally prepared to deal with them. To make biology teachers aware of what they might be confronted with, we discuss three kinds of misconceptions that are common in creationist literature: misconstruing scientific methodology, making a straw man out of evolutionary theory, and demanding unreasonable evidence. We offer some suggestions as to how to deal with them, but we also note the importance of embedding this approach in a more comprehensive educational programme in which students learn to think critically and in which their moral concerns and worldview are taken into account. In addition, we invite biology teachers to reflect on their own knowledge and, if necessary, to refresh it by consulting accessible yet scientifically informed literature. Although our main concern lies with teachers in Europe, our approach might be valuable to biology teachers worldwide.

Keywords: teaching evolutionary theory; misconceptions; nature of science; creationism

Introduction

Although creationism, be it of the young-Earth, old-Earth or Intelligent Design variant, and resistance to evolutionary science are still widely considered to be exclusively North American phenomena, they have evolved into a significant global movement over the last decades, including in Europe (Graebsch and Schiermeier 2006; Cornish-Bowden and Cardenas 2007; Blancke 2009, 2010). Consequently, in 2007 the Council of Europe warned against 'the danger of creationism in education' (Council of Europe 2007). We are concerned that in years to come European biology and science teachers will be confronted more frequently with creationist challenges posed by their students, due to the increasing visibility of creationists within the public sphere, intensified creationist propaganda and persistent cognitive impediments for understanding evolutionary science.

Educational background and motivation

Numerous studies suggest that students hold many misconceptions about evolution and its main mechanism, natural selection (for an overview, see Gregory 2009). Other studies suggest that students' misconceptions of the nature of science can impede their understanding and acceptance of evolutionary theory (Hokayem and BouJaoude 2008; Lombrozo et al. 2008). Importantly, these frustratingly persistent misconceptions (Bishop and Anderson 1990) might be

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due to cognitive predispositions that are hard to overcome by instruction (Kelemen and Di Yanni 2005; De Cruz and De Smedt 2007). Several of these cognitive predispositions are more in line with creationism than with evolutionary theory. For instance, the tendency to misidentify purpose (teleology) in the living world naturally develops in young children and lay people, without need of explicit instruction. However, around the age of 10, children undergo a cognitive shift by which they become more inclined to prefer natural over teleological and creationist explanations for phenomena in the natural world (Evans 2000; Kelemen and Di Yanni 2005). These findings suggest that educational efforts towards understanding of evolution may be better targeted at children over 10 years old. However, even after making this cognitive shift, children (and adults) may still be prone to teleological explanations of nature, and thus susceptible to misconceptions about evolution. For example, some studies (eg Kelemen and Rosset 2009) show that even educated adults continue to make incorrect teleological inferences when put under time pressure, endorsing statements such as 'Earthworms tunnel underground to aerate the soil'.

In light of the cognitive preference for teleological explanations, and the pervasiveness of creationist propaganda fuelling these misconceptions, we think it is important for teachers to actively engage with prior beliefs and misconceptions brought to the classroom, demonstrate how and where these go wrong and explicitly replace them with scientific concepts (Alters and Nelson 2002; Cunningham and Wescott 2009; Gregory 2009). As Verhey (2005, 997) puts it: '[S]tudents must "unlearn" before they can learn.' We argue that misconceptions about evolutionary theory and about the nature of science need to be addressed in the same breath, by confronting students with empirical evidence and by providing analogies that clarify the nature of scientific inference. In this way, students not only experience evolutionary theory as proper science (Nelson 2007), but they also gain direct access to the way science works (Pennock 2004).

Unfortunately, however, studies consistently show that teachers – even biology teachers – hold misconceptions similar to those entertained by students (Rutledge and Warden 2000; Rutledge and Mitchell 2002). Moreover, some studies indicate that up to 50% of teachers find it hard to accept the place of evolutionary theory in the science curriculum, preferring to 'balance' it by teaching creationism, or to leave evolution out of their classes altogether (Nehm and Schonfeld 2007; Nehm et al. 2009). This is not only the case in the USA. Research in South Africa and the UK suggests similar attitudes in teachers. They, too, hold many misconceptions about science in general and evolutionary theory in particular. For instance, they consider the word 'theory' to denote an educated guess, or they think humans have evolved from apes and monkeys. This leaves them highly vulnerable to creationist propaganda (Cleaves and Toplis 2007; McCrory and Murphy 2009; Sanders and Ngxola 2009). It seems that not all teachers are well prepared to deal with possible creationist challenges.

In this article, we do not intend to offer a catalogue of common misconceptions (for such a list, see *eg* Gregory 2009). Instead, we will discuss three major *kinds* of misconceptions creationists repeatedly level against evolutionary theory. First, creationists question the scientific status of the *methodology* of evolutionary theory. Second, they misconstrue the *content* of the theory to make it easier to discard. Third, they demand *evidence* evolutionary scientists cannot deliver in principle.

Some creationist organisations have openly and actively motivated students to introduce these kinds of misconceptions in the classroom (Wells, nd). Due to the intensified creationist propaganda in several parts of Europe, we think European teachers can increasingly expect to find themselves challenged by exactly these kinds of misconceptions in the classroom. As European science teachers may be less familiar with typical creationist fallacies, we consider it important and even necessary to provide a general overview of this problem. If teachers are aware of the most common misconceptions, they can prepare themselves to deal with them adequately. Therefore, we will illustrate each misconception with at least one example and offer some suggestions as to how to deal with them.

We fully realise that simply addressing and correcting these misconceptions concerning evolutionary theory, science and evidence will not suffice for making creationist students understand and accept evolutionary theory. One obvious difficulty is that some biology teachers also endorse creationism to some extent. These teachers have what Kitcher (2008) has termed hybrid epistemologies – they accept the bulk of scientific knowledge about anatomy, ecology, and so on, but let themselves be guided by religious convictions in the case of evolutionary theory. However, the problem of creationism in biology teachers falls outside the scope of this paper, since we focus on the challenges encountered by teachers who try to bring evolutionary theory across. In order to adequately deal with this resistance, teachers would also have to improve students' reasoning skills (Lawson and Weser 1990; Lawson and Worsnop 1992), address their moral concerns (Wilson 2005; Lombrozo et al. 2006) and take their worldviews and religious opinions into account (Anderson 2007; Reiss 2009; Schilders et al. 2009). However, one can only accept a theory if it is properly understood, so our account at least provides a first step towards addressing this problem. Moreover, teaching is usually a social event. Even if students with solid creationist beliefs are not so easily convinced, the misconceptions they raise might spark confusion in the minds of other, less religious students, if they are not properly dealt with. Or perhaps a student just wants to challenge the teacher with a creationist argument he or she picked up elsewhere. If these arguments are ill-addressed, or remain unaddressed, then this might have a negative effect on the students' understanding and acceptance of evolutionary theory. Therefore, dealing with misconceptions may not always be sufficient to counter creationist beliefs, but it most certainly is a necessary condition for teaching evolutionary science more efficiently.

The science behind evolutionary theory

'Evolution is not truth; it is merely an hypothesis – it is millions of guesses strung together. It had not been proven in the days of Darwin (. . .). It had not been proven in the days of Huxley, and it has not been proven up to today' (Bryan 2007, 158). These words were written by William Jennings Bryan (1860–1925) in 1925 as part of the summary argument he intended to present at the end of the famous Scopes trial. Due to circumstances, he did not get the chance to read it out loud (Larson 1997). Nonetheless, this quote is a clear expression of an objection that creationists have repeatedly raised against evolutionary theory: evolution is not science, because its methods are unsound. Bryan's objection was not new (Rudolph and Stewart 1998). When Darwin published his *On the origin of species* in 1859, he received a wave of criticism that doubted the validity of his methods. Among his critics were the most important philosophers of science of that time: John Herschel, William Whewell and John Stuart Mill. They considered the inductive method set out by Francis Bacon and exemplified by Newton's physics as the hallmark of proper science (Rudolph and Stewart 1998; Hull 2009). This means that one observes events and conducts experiments without any preconception and makes generalisations from the data generated by those observations and experiments. Herschel, Whewell and Mill rejected Darwin's theory because he had abandoned the strict Baconian approach – Darwin's ideas might make for good hypotheses, but they were not proven at all (Hull 2009).

Contemporary philosophers of science (*eg* Pennock 1999) and scientists (*eg* Ayala 2009) agree that Herschel and Whewell had taken too strict an approach to the inductive method. Ironically, Darwin's 'one long argument' in *On the origin of species* is now considered as one of the greatest examples of what Whewell himself termed a 'consilience of induction'. In spite of these developments in the philosophy of science, some creationists, especially of the young-Earth variant, still defend the outdated notion of science as a strictly inductive endeavor. Henry Morris (1974a, 4) wrote that 'it is impossible to prove scientifically any particular concept of *origins* to be true [. . .] the essence of the scientific method is experimental observation and repeatability.' Duane Gish (1978, 13), a renowned creationist debater, remarked that:

> for a theory to qualify as a scientific theory, it must be supported by events, processes, or properties which can be observed [...] no one observed the origin of the universe, the origin of life, the conversion of a fish into an amphibian, or an ape into a man. No one, as a matter of fact, has ever observed the origin of a species by naturally occurring processes. Evolution has been *postulated*, but it has never been *observed*.

It seems that creationists will only be convinced if they are put in a time machine and actually witness macro-evolutionary change. To see just how strange this requirement is, think of a detective arriving at a crime scene (Dawkins 2009). Of course, the detective did not actually witness the murder, but from the fact that there is a dead body lying on the ground with a knife stabbed in its back, he can reasonably and safely infer that a murder has taken place. On the basis of other clues he infers that the perpetrator forced his or her entry in the room (glass of one of the windows is scattered on the floor), that he or she is left-handed (from the angle by which the knife has entered the body), etc. The reasoning of scientists is actually very similar. Like a clever detective, Darwin (1859) inferred from the geological record the geographical distribution of species, homologies, vestigial and rudimentary organs, and embryological data that life on earth evolved by natural selection. Since then, this conclusion has been continuously confirmed by new evidence, such as molecular biology or genetics. However, creationists have one advantage: their model of science appeals to a conception of science entertained by students themselves and the public at large. In this view, science is about doing experiments in laboratories and making direct observations. Even the educational system tends to propagate this outdated model of science, with its emphasis on technology and laboratory work (Rudolph and Stewart 1998). Presenting evolutionary theory as good detective work might facilitate students' understanding of how science in general is conducted and help them accept evolutionary theory as proper science. Analogies from everyday experience like these may help students appreciate how the available evidence bears on a scientific hypothesis.

Evolutionary theory

Creationists not only misunderstand and misrepresent the methodology that supports evolutionary theory, they also make a straw man out of evolutionary theory itself. For instance, evolution is invariably equated with mere 'chance'. According to creationists, believing in evolution amounts to believing that, in the image of Fred Hoyle, one can get a Boeing 747 by letting a tornado whirl through a junkyard. Henry Morris (1974b, 156), for instance, wrote that '[t]he essence of evolution, of course, is randomness. The evolutionary process supposedly began with random particles and has continued by random aggregations of matter and then random mutations of genes.'

A more recent passage is found in *The evolution deceit*, written by the Turkish creationist Harun Yahya (1999, 158):

> Evolutionary theory asserts that life is formed by chance. According to this claim, lifeless and unconscious atoms came together to form the cell and they somehow formed other living things, including man. Let us think about that. When we bring together the elements that are the building-blocks of life [. . .] only a heap is formed. No matter what treatment it undergoes, this atomic heap cannot form even a single living being. If you like, let us formulate an 'experiment' on this subject [. . .]: Let evolutionists put plenty of materials present in the composition of living beings [. . .] into big barrels. [. . .] No matter what they do, they cannot produce from these barrels [. . .] giraffes, lions, bees, canaries, horses, dolphins, roses, orchids, lilies, [. . .],or millions of other living beings such as these. Indeed, they could not obtain even a single cell of any one of them.

Harun Yahya – actually the name for a writers' collective led by Adnan Oktar – replaces the image of a junkyard with a barrel, but the idea behind it remains the same. The analogy conveys the message that evolutionary theory says that complex phenomena in nature arise by chance, and chance alone: stir up the elements a bit, and you get wonderful complex organisms.

The equation of evolution with mere chance is also essential for the case of Intelligent Design proponents. It seems to make their explanation of biological functional complexity in terms of an intelligent designer much more plausible. An important part of the defence of 'irreducible complexity' – the notion distilled from creationist literature from the 1980s by Michael Behe in his book *Darwin's black box* (1996) – rests on the assumption that evolution occurs by pure chance. Behe argues that the bacterial flagellum (the bacterium's tail) has to come about all at once. Of course, given the complexity of the flagellum, this is a very unlikely event, which induces Behe to infer an intelligent designer. The flagellum is actually Behe's Boeing. William Dembski, the other main theorist of Intelligent Design, introduced an 'explanatory filter' to detect instances of design. However, if one takes a closer look at the filter Dembski puts forward, it becomes clear that he simply ignores the possibility of natural selection. The filter jumps from 'necessity' (explaining something by referring to a natural law) over chance to design as possible explanations of natural phenomena (Dembski 1999). However, as critics of creationism have pointed out repeatedly, natural selection is the opposite of chance: functional complexity occurs through the interplay of chance *and* necessity. Evolution is the *non-random* selection of *random* variations and mutations. A good pedagogical illustration of the crucial difference between pure chance and cumulative selection is given by Richard Dawkins' WEASEL program (Dawkins 1986). The odds against a computer producing METHINKSITISLIKEAWEASEL, a phrase from Shakespeare's *Hamlet*, in one shot – *ie* by pure chance – is 26^{23} to 1, a very small probability. However, if one allows the computer to preserve the right letters on the correct places at each attempt, it will need no more than 23 × 26 (= 598) attempts to get to this sentence (Dawkins 1986).

Students often have difficulties understanding the proper role of chance in evolution by natural selection, and it is therefore instructive to use illustrations like these. It will also make students less vulnerable to creationist obfuscations. Experimental evidence (*eg* Gigerenzer and Edwards 2003) indicates that people unfamiliar with probability theory make persistent errors when they have to calculate the probability of single events. Even medical doctors erroneously think that, if a breast cancer screening has a reliability of 80%, this means that, of all people with positive screening results, 80% actually have breast cancer. This completely ignores the base rate of breast cancer incidence in a population, and the possibility of false-positives. However, when probability is formulated in terms of frequencies, rather than single events, lay people perform much better. In this case, they heard the following scenario: 10 out of 1000 women over 40 have breast cancer; 8 of those 10 with breast cancer will test positive; 99 of the 990 women without breast cancer will also test positive. How many of those who test positive actually have breast cancer? This time, about half of the participants arrived at the correct response, which is about 8%.

When people think about adaptations in singular terms (*eg* a single structure coming into existence in Harun Yahya's barrel, the bacterial flagellum), we can likewise expect them to make incorrect inferences about the probability of such structures coming into existence. Teachers can avoid these incorrect inferences by stressing the gradual and cumulative retention of favourable variations and by explicitly representing natural selection in terms of natural frequencies, for instance, in terms of populations with natural variation (De Cruz 2009). The adaptive change in fur coloration in deer mice (*Peromyscus maniculatus*) is a pertinent example: due to the emergence of sand hills in their habitat during the past 10,000 years, the normally brown deer mice became more visible to birds of prey, which led to the spread of a rare light coat coloration mutation, which is now common in the population (Linnen et al. 2009).

Evidence

The issue of evidence has already come up in the previous sections, as the kind of evidence one demands for a theory naturally depends on one's understanding of that theory and the evidence in its support. We mentioned that creationists ask for a film of evolution, from molecule to man, because they insist that is the way proper science should be done. Ken Ham, president of *Answers in Genesis* (the largest American young-Earth organisation), keeps urging young children to ask their teacher: 'Were you there?' whenever they are taught evolutionary theory. If science indeed has to proceed the way creationists think it should, evolutionary scientists would have to come up with direct observations of macro-evolution – this would be like asking a historian to show Julius Caesar actually crossing the Rubicon River, or a particle physicist to directly demonstrate the existence of elementary particles. However, scientists can rely on other sources of evidence to support their conclusions, such as fossils or comparative studies of genomes.

Because creationists equate natural selection with pure chance, they want to see complex functional traits – the eye, the defence mechanism of the bombardier beetle, the bacterial flagellum – emerge in an instant. Harun Yahya challenges scientists to stir a molecule soup as long as they want, and see if they are able to obtain a single living cell, let alone a species. However, since evolutionary scientists never think of natural selection as a purely random process, they find Yahya's experimental challenge completely irrelevant.

Two more examples will show just how unreasonable some of the creationist demands for evidence are. In his book *The edge of evolution* (2007), Michael Behe mentions research conducted with yeast that showed massive gene duplication occurring within a common yeast ancestor. Gene duplication is considered a main source of new material for natural selection to work with. When a gene that is necessary for the development of a particular phenotypic feature gets doubled within the genome, the copy of the gene *might* evolve to perform something interesting itself, given a bit of luck and a selecting environment. It *might*, but nothing in evolutionary biology says it has to. On the contrary, it is much more likely that the second, unnecessary gene will remain inactive. In this case, within some species of yeast, the whole genome was duplicated at once. According to Behe, this surely is a huge opportunity for natural selection to demonstrate its craftsmanship. However, as he noted (Behe 2007, 74), nothing really interesting happened. From which he concludes that '[r]andomly duplicating a single gene, or even the entire genome, does not yield new complex machinery; it only gives a copy of what was already present.'

Of course, duplicating a gene only yields a copy of a gene already present. That is exactly what gene duplication means. Behe, however, wants this process to bring about complex features at a stroke. He seems to believe that natural selection *always* has to come up with something new and complex and that, if it doesn't, the creative power of natural selection is proven to be ineffective. But scientists *know* that gene duplication by itself does not produce complex features and evolutionary biologists do not pretend otherwise. Natural selection is about adapting organisms to their environment, and that doesn't always mean making them more complex.

It may seem unlikely that students will come up with this sort of sophisticated argument in the classroom, but on the other hand, the example highlights two common misconceptions concerning evolutionary theory and the evidence supporting it, which students may well bring into the classroom: (1) the equation of evolution with mere chance; and (2) the idea that natural selection invariably *has* to come up with novel adaptive complexity. The misconception of evolution as some kind of unrelenting progression, usually with humans at the end, is very persistent. In order to tackle these misconceptions, teachers should be constantly aware of what the theory of evolution by natural selection actually predicts, and how the evidence relates to the theory.

Next to this, creationists frequently refer to the supposed 'gaps' in the fossil record, asking for the 'missing links' that could fill them. Although fossils are only formed and preserved in rare circumstances, paleontologists have found plenty of fossils of transitional species: *Archaeopteryx*, for instance, illustrates the transition from dinosaurs to birds; the recently discovered *Tiktaalik rosae* sheds light on the transition from aquatic to terrestrial animals; and *Australopithecus afarensis* illuminates the evolution of bipedalism in hominids. Although it is unlikely that one of these fossils is a direct ancestor of extant species, they do show how features of modern species gradually evolved out of earlier adaptations. For instance, *Archaeopteryx* had feathers, but it also had a tail, claws and teeth that the animal shares with dinosaurs. Creationists, however, are not at all satisfied with this evidence. Duane Gish

(1978, 90), for instance, replies that *Archaeopteryx* is clearly a modern bird: '[I]t had wings, it was completely feathered, it *flew*. It was not half-way bird, it *was* a bird.' Ad-hoc explanations are then presented to account for the reptilian features. For example, Gish points out that claw-like appendages on wings can still be found in birds living today, so why would there not be birds with such features in the past? It is important for teachers to be able to explain exactly how transitional species constitute evidence for evolutionary theory and why these creationist remarks are completely mistaken. Claw-like appendages of modern birds do not contradict, but actually confirm, the reptilian ancestry of birds. The recent find of the feathered and probably flightless small dinosaur (theropod) *Anchiornis huxleyi*, which significantly predates *Archaeopteryx*, adds further evidence for the gradual evolution of birds from reptiles (Hu et al. 2009). It is important for teachers to have some knowledge of the available fossil evidence and to realise that, whenever there is a purported gap in the paleontological record, this does not entail the decline of evolutionary theory (Coyne 2009; Dawkins 2009).

Implications for education

To be sure, we realise that merely addressing students' misconceptions will not suffice to teach evolutionary theory properly. Correcting their mistakes will not make students suddenly change their mind. Therefore, this approach should be embedded in a comprehensive programme in which students not only learn to think critically, but in which their worldview and moral concerns are also taken into account. It is one thing to give people the freedom to choose their personal (religious) worldviews, but quite another to offer them substandard scientific education, as when teaching Intelligent Design alongside evolutionary theory. We believe that confronting students with their misconceptions in the scientific domain and explicitly replacing these misconceptions with correct alternatives is a vital part of good science education. Tolerance of beliefs that clash with scientific knowledge (such as the authority that evangelical Christians accord to the Bible) is not to be confused with giving equal time to controversial and unscientific material. Thus, teachers can express tolerance for such alternative worldviews, but indicate that they have no place in the biology class.

Ideally, strategies for dealing with creationist challenges should be supplied during teacher training. This would involve introducing future biology teachers to the way science works, and making them familiar with the overwhelming evidence for evolutionary theory. For instance, introducing philosophy and history of science in the curriculum of future teachers might be helpful to give them a feel for the way science works, and for the relationship between theory and evidence in scientific practice. Teachers should be on the lookout for analogies from everyday experience to transmit concepts that are intuitively difficult to grasp, such as the combination of chance and necessity in natural selection. Finally, biology teachers could get regular updates on new empirical findings that support evolutionary theory, for instance in the form of websites explicitly aimed at them (see *eg* www.evolutietheorie.be for an example in Dutch or http://www.bbc.co.uk/sn/prehistoric_life/dinosaurs/ for the UK). In practice, however, we think it is also important for biology teachers to be aware of the risk of being challenged in the classroom. We would advise them not to take their own knowledge for granted, and to refresh their understanding of the methodology of science, evolutionary theory and the evidence supporting it. This can be achieved by consulting one or two excellent popular scientific works such as Coyne (2009), Dawkins (2009), or Shubin (2008). These can supply teachers with the necessary information to adequately deal with students' misconceptions.

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