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Learning about astrobiology: a challenge for the public understanding of science

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Abstract:

Over recent years the importance of the public understanding of science has been increasingly recognised. Science is not only a core area of culture, but is also a major area of investment from public expenditure. Awareness of the potential of science to develop technologies which can safeguard and extend the quality of life - for example, through medical advances - is matched by knowledge of the role science has played in developing increasingly effective mass weapon systems and in facilitating the non-sustainable exploitation of natural resources. The public has a somewhat ambivalent view on whether science is in general a good thing, and scientific careers are not seen as attractive to many talented young people. Scientists in all fields must therefore engage with the issue of 'public relations' rather than consider their work as only the concern of an intellectual elite. Education for public understanding has become one of the responsibilities of those working in research areas funded from the public purse. Furthermore, spending money on aspects of 'space science' may not seem a priority compared with developing renewable energy technologies, tackling pollution and protecting biodiversity here on earth. Astrobiology has some advantages in this regard, being an area that can readily inspire the public imagination. Conversely, the very familiarity with aliens represented in mass media, may also mean that scientists attempting to explain the nature and significance of their work to the public may often face unhelpful preconceptions. Moreover, it can be argued that the areas of science that astrobiology draws upon (such as chemical, biological and cosmological evolution) are among those where research into science education has identified major learning difficulties. The present chapter offers an analysis undertaken from the perspective of science education, to discuss the nature of the particular challenges faced by those seeking to facilitate public education in the field of astrobiology.

Key words: astrobiology; science communication; public understanding of science; learning science; alternative conceptions; understanding evolution; constructivism

Learning about astrobiology: a challenge for the public understanding of science

Introduction

When the novelist and scientist C P Snow wrote about the 'two cultures' he drew attention to how even some of the most erudite intellectuals could claim ignorance of science almost as a badge of honour (Snow, 1959/1998). Whilst all well-educated people are expected to have some knowledge of Shakespeare, Picasso and Mozart, it is quite acceptable to not recognise names such as Bohr, Heisenberg or Dirac. Moreover, whereas being able to distinguish the music of Beethoven from that of Bach could be considered a fundamental prerequisite to be considered cultured, understanding something of Einstein's work would commonly be considered the preserve of 'boffins'.

Despite this, the importance of science education has long been recognised. For example, in the UK, debates about how science could best be learnt in the schools date to the late nineteenth century (Jenkins, 1979). The launching of Sputnik by the CCCP (USSR) brought into focus the need for effective science education in the US, seen as essential to provide the scientific and technological workforce necessary for a country's economic success. This is certainly a lesson that has been taken very seriously by some of the world's fastest developing nations, and remains a strong motivation for prioritizing 'STEM' (Science, Technology, Engineering, Mathematics) education around the world (Jenkins, 1997).

The importance of scientific literacy

However, in recent years, there has been growing awareness that the importance of science education does not solely rest on its utility for the minority of pupils who will go on to study science at higher levels and take up scientific or technical careers. Science education must meet the needs of *all* learners, and that has increasingly been related to developing 'scientific literacy' (Millar & Osborne, 1998). The gist of the argument is that we *all* live in a world where science and technology have major impacts, and therefore we all need to be able to engage with science with confidence and an awareness of both basic scientific ideas and something of the nature of what science is (Taber, 2006).

At a mundane level, as consumers, we are inundated with products claiming technological edge. The critical consumer has to ask, *inter alia*,

- Is there genuine added value in having protein in our shampoo, or five blades on our razor?
- Can more expensive washing powders wash our clothes whiter-than-white; and do the added enzymes really 'digest' stains?
- Will magnets in our pockets clean our blood; or copper bracelets ward off rheumatism; or crystals hung around our necks focus some form of spiritual energy?
- What is the evidence that acupuncture can cure disease, and are there any explanatory mechanisms for how it could work that are consistent with our current understanding of anatomy, physiology and biochemistry?

On a more collective scale, governments have to make decisions informed by scientific knowledge: whether to build nuclear power stations; whether to allow 'genetically modified' (GM) produce onto the market; when to close schools to avoid the spread of pandemics, etc. Whilst some of these decisions will rely heavily on recommendations from scientific advisors, in a democracy such decisions have to be explained and justified to the public. If the public does not want nuclear power or GM ingredients in their foodstuffs, they can express their views – ultimately through the ballot box and so remove governments that make unpopular decisions. A scientifically literate electorate is more likely to be able to understand and weigh-up the arguments made in such debates.

This may be especially important when things go wrong. The Three Mile Island accident has been used to suggest nuclear power is not safe. Popular accounts disagree on how close that incident came to becoming a major disaster. The Irish government has objected to radioactive material detected in their coastal waters, originating in discharges from a nuclear reprocessing plant on the Western coast of England. The public has to decide whether the level of radioactivity detected is a sign that the English facility is releasing dangerous amounts of material, or just evidence for the excellent sensitivity of modern detectors. Even the Chernobyl 'disaster' can be interpreted in very different ways: showing that nuclear power is inherently unsafe, or demonstrating that even a major nuclear accident is fundamentally no worse than other major industrial mishaps – such as at Seveso in Italy or Bhopal in India. And how do members of the public decide if it is ethical to continue to produce nuclear waste that will be 'hot' for many thousands of years, when there seems to be limited consensus on the degree to which we have already identified safe and secure methods of long-term storage? Such issues can only be understood by those with some scientific knowledge and understanding – but the vote of a citizen who is scientifically literate carries no more weight than the vote of one who is largely ignorant of science and technology.

In recent years it has become increasingly clear that there is more at stake here than just industrial progress and economic success. We are told that the planet's biological diversity is being lost at a vastly increased rate, and that this is due to human actions. Many of the believed-to-be-lost species have never even been characterised, and so have never been economically important to humans. Without some understanding of ecology, the arguments for the inherent importance of diversity may seem subtle for people who cannot see how the extinct species could have been harvested and processed to meet their immediate needs.

Forests are disappearing, and deserts are growing – but some argue that such change is 'natural' (by which they mean independent of human action) and inevitable. Climate change is now widely accepted in scientific circles, but again the arguments about the evidence for change, and the possible consequences are complex. If one politician warns of impending disaster, but another rejects the global warming scenario, then the public is likely to be confused. Such a scenario was played large in US politics where the election of a President who did not accept the scientific case for climate change 'hung' on judgements about whether tiny hanging chads of card represented intended votes or incidental damage to voting papers. Whereas the man deemed elected to the highest office in the most powerful nation delayed action on greenhouse emissions for years, his presidential rival went on to be awarded a Nobel prize for his efforts to make the case for action. There were of course many substantive issues separating the two candidates, but the close and disputed nature of that election highlights just what is at stake in having an electorate that is well-informed on scientific issues.

It is important to reiterate that scientific literacy is not just about understanding some science, but just as much about understanding the nature of science itself – how it 'works' (Millar & Osborne, 1998; Taber, 2006). When scientists cannot agree on how quickly climate change is taking place; how conditions will change in different parts of the world; and when we cannot know for sure whether the process may soon reach another local 'attractor' in the ecosystem (to leave surface conditions stable but slightly different) rather than slip into a runaway greenhouse that could turn Earth into a twin of Venus, then the casual observer might question how certain any of the relevant science is.

Scientists are skeptical by training and profession - the only thing we really know is that we can not be absolutely sure of anything we know – and so a lack of absolute certainty is part of the familiar intellectual landscape for anyone working in science. For the lay person, technical debates about ‘how much’ and ‘how quickly’ may seem a good reason to delay until the scientists can actually agree that they really know what is going on. However, this is one case where waiting for definitive empirical data is not an option: after the ‘experiment’, the findings may prove to be of purely academic interest if we are left with an uninhabitable world. Arguably, public levels of scientific literacy could here be crucial to decision-making that might determine whether Earth remains hospitable to humans and many other species over the coming decades and centuries. (And so whether Earth remains of interest to potential astrobiologists from elsewhere as a source of collaborators - or simply an archaeological field site!)

The public sponsorship of science

A major consideration is that much science is publicly funded. Decisions have to be made about which science projects to fund from finite public resources. When US President J F Kennedy announced that man would go to the moon he took up a challenge that was widely supported: certainly within the US, where the notion of a ‘space race’ with the Soviets helped maintain support. The importance of metaphor (Lakoff & Johnson, 1980) is such that common US public perceptions of the Soviets as an enemy (and their Communist comrades in China as a potential ‘peril’) was a strong motivator for supporting international *competition*. In a post ‘cold-war’ World it is questionable whether such a priority would have received similar levels of strong support. The greater degree of international *cooperation* in today’s space programmes is certainly to be welcomed; but many question prioritising large sums of public money for space science whilst much of the World’s population faces unnecessary starvation or early death from preventable disease. The potential of findings to inform decision making about issues vital to living on earth may not be immediately obvious.

Perhaps walking on the moon, another world, offered a particularly appealing target in the way that maintaining an international space station, just on our planetary ‘door-step’ by comparison, or sending unmanned probes out into the solar system, does not. There is a complex issue to be untangled here. The science of the international space station, or even of the Hubble telescope, is not so readily sold. Putting people into space may even seem foolhardy. The loss of Apollo 1 may be presented as heroic even if the danger of mixing electrical switches and an oxygen-rich atmosphere seems obvious in retrospect: the losses of Challenger and then Columbia tend to be seen more as a matter of casual incompetence.

The ‘Public Understanding of Science’ as an emerging field

For most people, formal science education ends when they leave school. Although a proportion of school-leavers continues to study science in post-compulsory education, most people do not attend formal science lessons in their adult years. This makes school science extremely important: but there is much evidence that for many adults who have passed through the school system, their understanding of science leaves much to be desired.

So there have been many surveys claiming to show that substantial proportions of the populations of developed nations (such as the US, and the UK) fail to appreciate the kinds of basic scientific facts and principles that Lord Snow might have argued should be part of the common heritage of any cultured person.

Moreover, significant proportions of some populations give as much credence to superstitions such as astrology as to science, and many do not accept such a well-established scientific principle as the evolution of life on earth. So Oliveira (2008: 24) reported in 2008 that “in a Republican Debate, three candidates to the Presidency of the United States of America stated that they do not believe in evolution”. That is clearly an issue for scientists who wish to disseminate their findings to the public if they are working in astrobiology – a field which is “generally seen to be a science concerned with ‘the origin and evolution of life in the Universe’ or derivations of this theme” (Cockell, 2002: 263) and which “studies life in the universe, its origins, evolution and distribution” (Rodrigues & Carrapiço, 2006: R-1).

Indeed, there is now even a significant minority in some countries who do not believe that the Apollo programme actually got people to the moon. It has been suggested that “as many as 20% of the US population believe that the Moon landings did not take place but were faked by NASA in a television studio on Earth” (Jones, 2004: 47). Even if (as one might hope) this figure is unreliably high, this still seems a worrying finding from a population that is so easy sold a wide range of incredible ideas and dubiously enhanced products.

Scientists themselves increasingly recognise the importance of informing the public about their work, citing a range of reasons including “public accountability; a better informed public; generating support (financial, social, political) for specific areas of science and engineering; [and] recruitment of students” (The Royal Society, 2005: iv).

In recent years, then, there has developed an active field of *the public understanding of science* (PUS), which has evolved somewhat interpedently of traditional science education. Science education is more firmly established as an academic field (Fensham, 2004), but has traditionally been concerned largely (if not exclusively) with science learning and teaching in formal contexts (Taber, 2009a). The field of PUS, however, is commonly associated with what is termed 'science *communication*' rather than science *education*. It will be suggested below that this could be a significant hindrance if the PUS movement wants to change people's minds.

PUS has also been associated with the notion of the 'science wars', i.e. taking the side of science against influences in society that are seen as being 'anti-science'. A major difficulty here is that there is no clear consensus on whom the 'enemies of reason' (a term used for example by the inaugural holder of Oxford University's Chair in PUS, Prof. Richard Dawkins) are, or more fundamentally even, on what science actually is.

So religion is seen as an archenemy of science by some commentators: but clearly not by those many active scientists from different religious backgrounds who see no contradiction between their science and their faith (Barbour, 2002). Presumably many of those who practice astrology, Feng Shui, clairvoyance, voodoo and a wide range of other practices that most scientists would frown upon, consider themselves to be working in an established tradition developing a practical craft and/or system of knowledge through a combination of empirical investigations and received wisdom. That is, whilst those in the science camp may claim these practices are neither systematic, nor based on critical examination of evidence: they may be considered by their genuine supporters to meet both these criteria. As Carl Sagan (1995: 10) commented: "People are not stupid. They believe things for reasons. Let us not dismiss pseudoscience or even superstition with contempt". Scientists commonly give great weight to prior authority, and regularly find ways to explain away inconvenient findings, and to an observer standing out side of the scientific community (and so lacking a detailed grasp on the issues), the grounds for doing so may seem no better justified than the arguments of a astrologer or psychic medium.

Marxism was meant to be a scientific approach to understanding socio-historical issues, yet is unlikely to be considered part of science by most professional scientists today. Freud certainly saw himself as working in a scientific tradition (Claxton, 2005), yet today his methods and conclusions are considered by many to be highly subjective.

Are either of these areas science? Freud's work is both widely criticised, and acts as the source of many valuable insights still informing psychiatrists today. Marxism's scientific credentials must for ever be sullied by their application under Stalin, and in particular, the Lysenko affair, where the adherence to Marxist doctrine took precedence over scientific values (Frolov, 1991): failure to defer to the desired conclusions meant career suicide or even imprisonment for scientists, and starvation for a great many in the wider population. Yet one of the thinkers most influential in education today, Lev Vygotsky (1978), undertook his work committed to and informed by Marxist principles. This is all the more notable as his own work was eventually censured by the State, and only become known and influential in the West decades later, long after his premature death. Others working in the Soviet system, such as Luria (1976; 1987) and the activity theorists (Engeström, Miettinen, & Punamäki, 1999), produced work which is still of great interest day. To decide whether Freudian psychoanalysis or Marxism can be considered part of science, we would need an agreed *demarcation* criterion. However, whilst there have been suggestions on what such a criterion should be, there is no general agreement and probably never could be.

Deciding what is or is not a part of science would surely have to be a consensual view of the scientific community: yet deciding who counts as part of that community depends upon the criterion chosen. In practice, there *is* widespread general agreement on who are scientists and what is science: but with a good deal of fuzziness around the edges. Science is perhaps understood as one of those concepts where it is easy to suggest exemplars or prototypes, but impossible to provide a definitive sharp boundary. The philosophers of science may individually be informative here, but are collectively unhelpful. Popperians are likely to exclude many activities admitted by followers of Kuhn or Lakatos, whereas Feyerabend would mischievously put a case for including many of those practices that are commonly seen as anti-science.

What is clear is that some of the common targets of the science side of this public debate are popular among lay people. So Halpern characterises the American public

> First, a large percentage start everyday by reading their horoscope and believe that it is so often correct that it's as though it was written especially for them; they phone their personal psychic, at a cost that many cannot afford, for advice on matters that range from how to invest their money to whether or not a loved one should be disconnected from life support systems; they spend huge sums of money on a variety of remedies for which there is no evidence that they work or are even safe to take — sometimes with disastrous results
>
> (Halpern, 2000) p.22

Halpern goes on to cite a study suggesting that even among college level students, "more than 99 percent expressed belief in at least one of the following: channeling, clairvoyance, precognition, telepathy, psychic surgery, psychic healing, healing crystals, psychokinesis, astral travel, levitation, the Bermuda triangle mystery, unidentified flying objects (UFOs), plant consciousness, auras, and ghosts". It should be noted this 99% figure did not specifically include formal religious beliefs, although for some taking the 'science' side in the perceived science wars, "belief in ESP, belief in God, and belief in the unluckiness of the number 13 all are tarred with the same brush" (Irwin, 1993: 4).

Astrology supports a community of practitioners who make a living from advising people based (supposedly at least) upon the arrangement of celestial bodies at the date and time of birth. In its most popularist form, even quite respected publications carry 'horoscopes' because many of their customers wish to read them. That these 'horror-scopes' tend to make claims of the sort that about eight percent of a population needs to be careful with money this week, or should look out for the needs of loved ones, or deserves to take some time for themselves etc, seems laughable to the scientifically-minded. Popular horoscope writers could surely just as easily find a rationale in their system to suggest that the end of the week would be a good time for those with one 'star sign' to carry out that planned criminal act, or that now is a good time for infidelity for those of another 'birth sign' whilst their loved ones are distracted: but they are presumably aware that such advice – no less based on any real evidence - would not be so welcome. Some scientific greats of the past (such as Kepler) took horoscopes seriously, but at least sought to cast them based on specific details of the individual concerned. However, many otherwise sensible people do not see why some scientists and skeptics get so agitated about this popular form of superstition, seeing it as nothing more than harmless fun.

Horoscopes are just one aspect of a long-standing tradition of using natural signs to interpret human concerns: be it the (effectively random) patterns in tea leaves or animal entrails or interpreting meaning in a sequence of tarot cards or through the use of the I Ching. If the people 'reading' these predictions considered them as a form of 'oblique strategy', then scientists would find them less objectionable. The composer and record producer Brian Eno is well known for using such techniques as an aid to overcome creative blocks with musicians. If the performers are stuck in a rut then they pick a random card that might suggest they swap instruments or try playing at half tempo or whatever. There is no pretence that the card somehow 'predicts' the right way forward, it just offers a way out of a rut, and introduces some variation that the artists' creative minds can take as a new starting point. If people looked for patterns in tea leaves in a similar expectation – like a do-it-yourself word association or ink-blot test, where the meaning is recognised to come from the interpreter not the stimulus – then these activities might be seen by scientists as no more than self-awareness aids, rather than dishonest appeals to supernatural forces.

The problem with horoscopes is, of course, the belief of many lay people that at some level there is ‘something in it’ - beyond the ability to focus people’s minds on specific aspects of their lives because of their suggestibility.

Learning science: constructing understanding and responding to misconceptions

One of the points made earlier in the Chapter was that the PUS movement has tended to be associated with what is commonly described as ‘science *communication*’ rather than ‘science *education*’. Perhaps this is meant as no more than a careful choice of terminology that seeks to avoid alienating the audience. After all, children are sent to school to be educated, where adult citizens seek rather to be informed. The latter are already educated, the argument might go, and science communicators offer information suitable for intelligent, educated adults. Perhaps. Perhaps also there is something of an identity issue here: science educators – it could be argued - are not real scientists, but just teach about other people’s work; whereas *real* scientists do the actual science and then communicate it as part of the overall scientific process. Again: perhaps.

In some ways the best people to communicate science might be the scientists themselves: they have the greatest knowledge of, and enthusiasm for, the science; they are in a position to speak with real authority.

These are all pertinent points. However, if the PUS movement is based on a premise that members of the public will change their minds if only they can be told about science first hand by those at the cutting edge, then this may prove a simplistic assumption.

The challenge of science teaching

Teaching is often seen by outsiders as about those with subject expertise informing - through telling, showing and explaining - those lacking that expertise, so that knowledge is ‘transferred’ from teacher to student. Although the terminology of 'transfer' is widely used, a better term for the process described would be 'copied': as the actual perceived aim is often that the teacher's knowledge should be copied to the minds of the students (Taber, 2009a).

If teaching is seen in these terms then 'science communication' would seem to *substantially* be no different to science teaching: teaching where the learners are often adults and not school children, and the communicator is a genuine subject expert talking about work they are intimately involved in, rather than just a teacher who has usually 'only' learned about the topic secondhand. Science communication could then seem to be something of a higher-grade version of science teaching.

Of course, I am going to suggest this is hardly the case. It has been known for some decades that carefully and well planned teaching by teachers with good subject knowledge is often insufficient to lead to attentive and motivated pupils acquiring the target knowledge set out in the science curriculum. A range of possible reasons for such failures to learn has been explored.

One approach considered carefully examining the structure of the subject knowledge itself to make sure that the teaching sequence adopted introduced material in the most logical order (Gagné & Briggs, 1974). Another area of research, associated particularly with the work of Jean Piaget (1972), explored the way in which a child's cognitive abilities develop, and suggested that many science topics were not within younger children's grasp (Shayer & Adey, 1981), not at least unless special care was taken to find ways to link them to children's experience (Bruner, 1960). A complementary approach has considered how the brain can be analysed as an information processing system (White, 1998), and has considered the significance of features (such as working memory capacity) that act as system 'bottlenecks' (Miller, 1968).

These different perspectives all offer considerations that do need to be taken into account in effective science teaching (Taber, 2009a). However, they have not proved to be enough. So whilst poorly sequenced, over-paced teaching with a cognitive demand beyond the learners' stages of development is certainly unlikely to bring about intended learning; it does not follow that well-sequenced, well-paced, and well-matched teaching will lead to students acquiring the target knowledge. These considerations are *necessary-but-not-sufficient* for good science teaching – there is something more that needs to be considered (Taber, 2001).

This 'something' is what the learner already 'knows'. Towards the end of the 1970s it became widely accepted that approaches to teaching science based on an implicit assumption that ignorance was to be replaced with knowledge were inadequate. It was found that school children, and even pre-school children, already had a lot of knowledge of many scientific topics (Piaget, 1929/1973). However this was not 'knowledge' in the philosopher's sense of *justified, true belief*: often what the child 'knew' was not well aligned with scientific knowledge, and so was at odds with what they were meant to learn in school – even if from the child's perspective there was good reason for their way of thinking about the topic.

Alternative conceptions of science topics

Often the science teacher was presenting a topic about which the children already had a good many ideas: some quite explicit, others tacit (but none-the-less influential in their thinking); some quite similar to the scientific models, but others that could be in complete contradiction. Clearly some of these ideas had significant potential to interfere with the learning set out in the curriculum.

A few examples of the kinds of student thinking about science topics that have been uncovered in research cannot do justice to the phenomenon, but will at least illustrate the general point. Probably at least four-fifths of students in most introductory physics classes have previously developed a way of thinking about force and motion at odds with Newtonian dynamics (Watts & Zylbersztajn, 1981). Most people's intuition is that a force is needed to keep something moving, and that in the absence of such a force a moving object will come to a stop. Research suggests such ideas are not readily extinguished by teaching, and that even if students dutifully learn the physics model for examinations, they often readily slip back into the 'alternative' conceptual framework when asked questions in a real-life context.

Whilst this example reflects one of the most common and widely explored alternative frameworks, it could be argued that students' ideas are not really wrong here (as in common experience a moving object *will* come to a stop in the absence of some driving force) – but just based on a different formalism (Taber, 2009a). After all, it can be asked, why does it make sense to derive a system that starts from assumptions of no air resistance, gravity or friction, when all familiar examples of objects in motion (footballs, sprinters, cars, planes etc) are found in a context where frictional forces and gravity operate?

However, a second example where such an argument is less supportable may be useful. Research suggests that by the time students get to study why reactions occur in high school or college chemistry (for example in terms of enthalpy changes), most have already developed their own alternative explanation. For most students chemical reactions occur to allow atoms to fill their shells (Taber, 1998). Again, this is an idea which seems to be resistant to change, and which students will offer even after being taught scientific models. Although this example has been less well explored in different populations than the so-called 'impetus' conception of motion, it is in some ways more telling. For one thing, it cannot be argued that students develop this idea because of the apparent behaviour of familiar examples: all children have extensive experience of objects requiring force to move them long before they formally study physics; but no child has direct experience of the electron movements during reactions to bring to the chemistry class. Even more telling, almost all common chemical reactions, certainly those studied in elementary science and introductory chemistry, are clear counter-examples to the common alternative conceptual framework (that is, reactions occur *despite* the reactant species nearly always already having atoms with full shells). Yet, for example, students asked about the reaction between H_2 and F_2 will commonly 'explain' that the reaction occurs because this allows the hydrogen and fluorine atoms to obtain full shells! When students can commonly hold such ideas in the face of apparently overwhelming counter-evidence, it is clear that effective science teaching can be quite a challenge.

The nature of prior ideas about science topics

A vast research programme has explored student thinking across most science topics at different student ages and in many countries (Duit, 2007). This research has used various approaches, but one of the most common and direct techniques is simply to interview children or students and to ask them to explain their ideas (Gilbert, Watts, & Osborne, 1985). To give a flavour of this kind of research, I present later in the Chapter a small extract from an interview with one thirteen year old school girl, Sandra, as she talked about her mental model of space.

Findings from this research programme have been diverse, and indeed sometimes led to considerable debate about what the actual nature of children's scientific thinking is. In retrospect, surveying the range of research undertaken, it now seems clear that children come to science lessons with ideas that vary along a wide range of dimensions (Taber, 2009a).

So whilst sometimes children offer ideas which are little more than romanced suggestions that they will readily drop, on other occasions learners' ideas have been found to be strongly committed to, and to be robust and tenacious enough to be relatively unaffected by teaching. Students' ideas may be similar to scientific ideas, or effectively orthogonal to them, or completely opposed. Sometimes, children's ideas about specific science topics are like conceptual islands with little connection with anything else they seem to know: on other occasions they have developed extensive, theory like networks of propositions into which ideas at odds with school science are well-integrated (Taber, 1998). Sometimes students entertain manifold ideas about a topic and shift their thinking according to the way a question is phrased, or from one example to another (Taber, 2000). However, at other times they have a core way of thinking about a topic that is widely applied across relevant contexts.

It is probably fair to say that children's thinking about science is just a microcosm for human thinking in general. Surely each of us exhibits this range of thinking patterns considering the various conceptual domains in which we operate: including those where we are experts as well as those where we are novices; and those where we have a strong commitment, and those where our interest and motivation are minimal. In view of this wide range of characteristics, it will not be surprising that there does not seem to be a simple prescription for the way that science teachers should respond to students' prior thinking.

Conceptual change in science

What this vast body of research has shown, however, is that the 'transfer' metaphor for science teaching is woefully inadequate. Science teaching is not about imprinting ideas on *tabula rasa*, or filling empty vessels with knowledge, it is often about engineering conceptual change.

Learners 'construct' their own knowledge by interpreting new information (whether from direct experience, or reported by others such as teachers) in terms of their existing ideas. This building process operates on quite small 'learning quanta' (Taber, 2005), so – to risk overextending the building metaphor – even if the teacher could make sure the learner was using perfect copies of the teacher's 'concept bricks', they were most unlikely to be used to form a conceptual structure that was a copy of the teacher's own knowledge.

There has therefore been quite an extensive research effort exploring both how conceptual change occurs in science, and how teachers can best engineer it in the classroom. Although there is no reason to assume that *science* education is unique in facing these challenges, as students will bring existing thinking to other school subjects, it has certainly been a strong focus of much conceptual change research (Vosniadou, 2008).

Yet despite the research effort applied to this issue over two decades, and some considerable progress in building useful theoretical perspectives (Chi, 1992; diSessa, 1993; Hammer, 2000; Strike & Posner, 1985; Thagard, 1992), we are still some way from being able to provide teachers with a single general purpose strategy to best shift students' alternative conceptions toward the scientific models, or even a set of strategies within a clear overarching theoretical model showing when to adopt each approach (Taber, 2009a).

What does seem clear is that effective science teaching calls upon at least three major areas of knowledge: subject knowledge of the science to be taught; pedagogic knowledge relating to what is known about the teaching and learning of the topic (for example, what the major learning difficulties are in a topic; which analogies students usually find accessible; which explanations they usually find persuasive); and knowledge of the students themselves. Good teachers engage in perpetual interaction: constantly seeking information about what students already know, what they think, what they understand, and judging how teaching is being interpreted; and use this diagnostic information as the basis for on-line problem-solving to inform the on-going teaching process (Taber, 2002). Needless to say, this is difficult enough in a one-to-one teaching setting, but is highly demanding is classroom contexts.

The challenge for 'science communicators'

Good science teachers are only ever partially successful in getting students to adopt scientific ways of understanding topics, even when they have strong knowledge in all three domains. Professional research scientists, acting as 'science communicators', will often have much deeper understanding of their specialist areas than school or college teachers who have to be familiar with a broad range of subjects and where the target knowledge is not the science itself, but the curriculum models which are designed to match learners at a particular grade level (Taber, 2008b). However, science communicators will often lack the detailed training in science pedagogy, and will often be delivering in non-interactive modes (books, media appearances, talks) where they have minimal knowledge of how what they are saying is being understood and interpreted by their audience. Given the difficulties of communicating scientific ideas faced by professional teachers working interactively with students they usually know well, the challenge for research scientists hoping to bring about conceptual change among an often remote and ill-defined target audience is surely that much greater.

Prior knowledge and learning about astrobiology

What is clear from the educational research literature, is that existing ideas influence new learning. Astrobiology-related ideas have a high profile in the public imagination, as life from other worlds has a well-established place in popular culture. Aliens are highly familiar among fictional characters, including some very well-liked ones: Superman, Mr Spock, ET, Dr Who, etc.: "Aliens abound in our common culture, despite the fact that we currently have no evidence for their existence" (Griffiths, 2004: 179). Although SETI (the search for extraterrestrial intelligence) is certainly part of the wider remit of astrobiology, there is much of great scientific interest that does not require sentient, intelligent aliens - but whilst scientists may get excited about possible traces of micro-organisms elsewhere in the universe, such forms of life are less salient in terms of capturing the public's imagination.

Where there has been a great deal of research into children's and older students' ideas about most school science topics, astrobiology as a field in its own right is an advanced area of study, and has not attracted much direct attention in the science education literature. However, there is much in that literature of relevance to the scientist interested in communicating astrobiology to the public.

Learning about the earth in space

One of the fascinating aspects of this area of research is how every individual is likely to offer some new slant on a topic, so that even the experienced interviewer can be surprised at some of the ways young people think. As an example, I will present a small extract of an interview with an English schoolgirl whom I will call Sandra. Sandra was one of a number of students at her school who volunteered to be interviewed as part of a project called the 'Understanding Science Project' . This project was unusual in that rather than focusing on a particular science topic, it was concerned with coherence and progression in student scientific thinking. Students were interviewed over a period of time (several years in the case of a number of students) and simply asked to talk about the science they had been learning in school.

At the time of the interview discussed here, Sandra was nearing the end of her second year of secondary school, so she will have been thirteen years of age. At this stage of her schooling Sandra was studying a topic about earth in space during her science lessons, and I had asked her to tell me about the topic. The extract begins just after Sandra mentions that one can see stars in the night sky.

> Keith: So what's a star?
>
> Sandra: I think it's like a big ball of like, electrically, fire-y sort of thing. … It's either a big ball of like electric-y stuff, or a big ball of like fire-y stuff. I'm not sure which one. …
>
> Keith: How can they tell if something is a star or a planet, do you think?
>
> Sandra: I think the planets are generally brighter?
>
> Keith: Why's that?
>
> Sandra: 'cause the sun's rays bounce off them. It's the sun's the only thing, apart from stars, that like has its own light source.
>
> Keith: So what's the light source of the sun?
>
> Sandra: It's like a big ball of fire.

The somewhat vague way of describing things (being like, sort of, thingy) was characteristic of Sandra's talk in these sessions, and seemed to be as much a way her group of friends generally conversed, as an indication of uncertainty.

Researchers interested in learners' ideas have to try to take a neutral stance in terms of not making assumptions beyond what the students tells us. However, researchers - just as much as learners - interpret what we are told through our existing conceptual frameworks, so it is easy to slip up. At this point in the dialogue I assumed that Sandra realised that the sun ('a big ball of like, electrically, fire-y sort of thing') was like any other star ('a big ball of fire'), just nearer.

> Keith: Okay, so this is like the big fire-y, electrically thing, yeah?
>
> Sandra: Yeah, except the sun's like really bigger … much bigger.
>
> Keith: So it's much bigger than the stars, is it?
>
> Sandra: Yeah.
>
> Keith: How do you know that?
>
> Sandra: Because you can see it.
>
> Keith: And you can't see the stars?
>
> Sandra: You can see the stars, but you can see that the sun is bigger than the stars.

> Keith: Well how big's the sun then?
>
> Sandra: very big … it's like bigger than earth, it's like bigger than all the planets.

I had not expected this response from Sandra who was a fairly intelligent adolescent with quite a strong interest in science and technology. I was also confident that she understood perspective, and the distinction between something being small, and being a long way away. However, playing devil's advocate I suggested that on the same logic (i.e. that the stars are smaller than the sun because they look smaller) then the sun must be much smaller than the earth,

> Keith: Oh that's just silly, because I've seen the sun
>
> Sandra: But it's like really far away.
>
> Keith: But the earth goes on as far as you can see, and the sun only looks that big [indicating with my hand].
>
> Sandra: Yeah but that's because it is really far away, and so it looks small.

So, as I expected, Sandra was perfectly aware that the larger of two objects will seem smaller when it is much further away. So, surely she could appreciate this possibility with the stars as well?

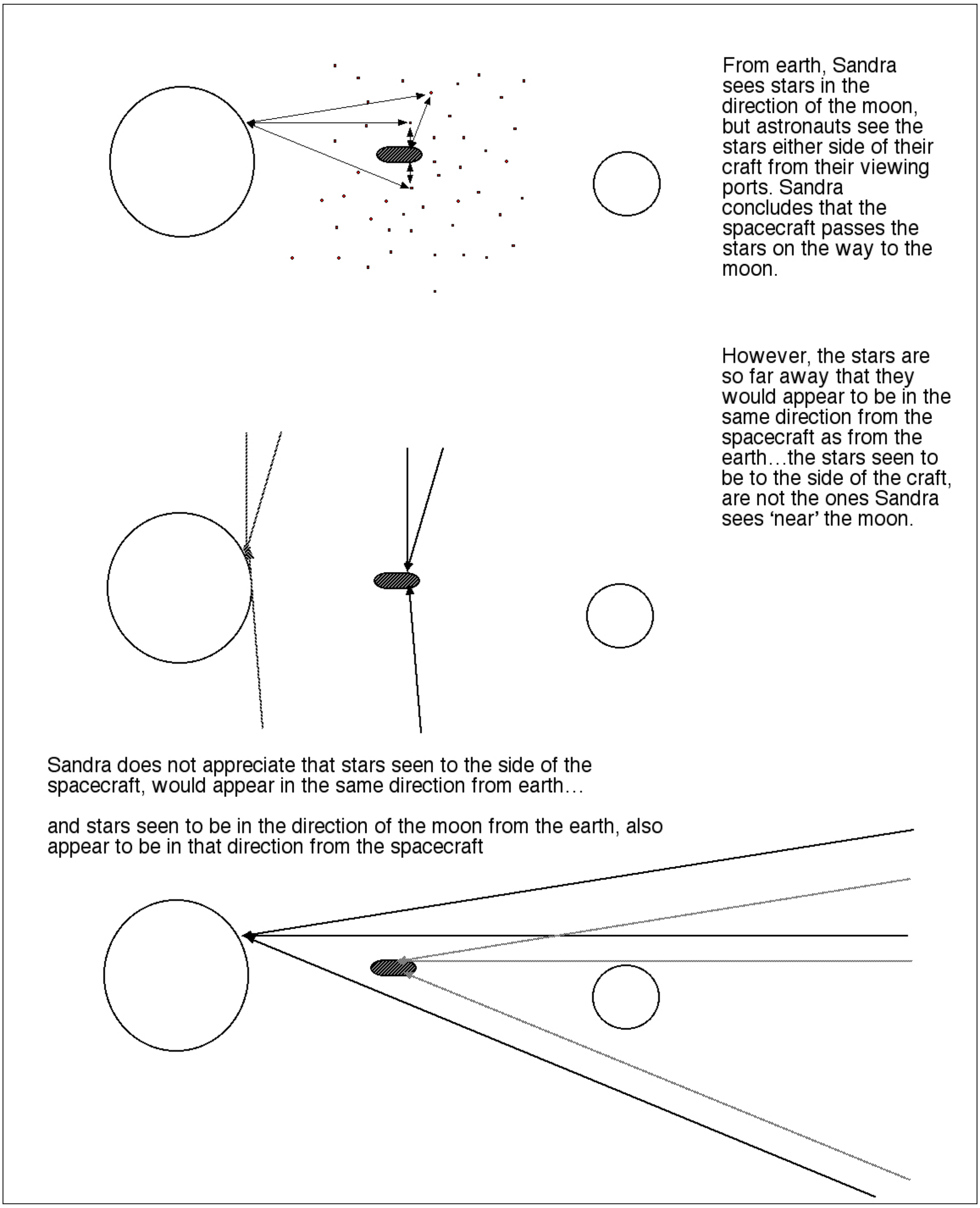
> Keith: So maybe the stars are even further away?
>
> Sandra: No, they're not.
>
> Keith: How do you know that?
>
> Sandra: Because, like, when you go into space, you go past stars.
>
> Keith: When you go where? Into space? [Unsure if I had heard correctly.]
>
> Sandra: When you go into space. [Said as if obvious and commonplace.]
>
> Keith: When have you been going into space?
>
> Sandra: I haven't, but other people have.
>
> Keith: How do you know about this?
>
> Sandra: Because like, it was recorded.
>
> Keith: Okay, and you've seen it on television or something, have you?

Sandra: Yeah.

I know from other interviews that Sandra did watch science and technology documentaries on television, and it seemed she genuinely believed she had seen this. Memory can be very unreliable, and we can often think we remember things accurately when objective evidence suggests otherwise. One interesting study asked students about what they thought was going on in the wires in a simple electrical circuit before, immediately after, and some weeks after a teacher demonstrated how current is conserved round a series circuit. Children commonly tend to expect that the current diminishes around a circuit, being progressively 'used up' at each load (such as a lamp). The study found that even when the teacher's demonstration seemed convincing immediately after the lesson, some time later some of the pupils 'remembered' the demonstration as offering clear evidence for their prior conception that the current will diminish around the circuit (Gauld, 1989).

It is not clear what Sandra had seen which led her to form this belief. Perhaps she was confusing documentaries with images from fictional programmes – such as Star Trek where from within spacecraft moving 'at warp' (i.e. at super-luminary speeds supposedly achieved by warping space-time itself) the star field can be seen passing by from viewing ports and screens. Perhaps she saw images of spacecraft such as the shuttle moving against the night sky, and later recalled that the craft was moving past the stars. Perhaps, however, she simply misinterpreted images of 'stationary' stars seen through the windows of real spacecraft according to existing prior knowledge: if there are stars to the left or right of a spacecraft travelling to the moon, and the stars seem to be above us, then surely they must be between us and the moon? (See figure 1). Whatever the origin of this alternative conception, there was nothing wrong with the logic that (based on a false premise regarding relative distances) deduced that stars are smaller than bodies such as the moon or planets.

Whilst this is just one example of a particular alternative conception elicited from one individual schoolchild, there is plenty of research suggesting that misunderstandings about space are common. So, for example, it has been found that youngsters commonly pass through a number of understandings of the relationship between the earth and the universe as they attempt to make sense of what they learn about the earth as a body in space in terms of their common experience of living on an apparently flattish and fixed earth, that people do not seem to fall off of. Students may think that the name earth is also given to one of those bodies out in space (so that earth is a round cosmic body like the planets, unlike this earth), or that the universe is like a sphere and the earth is the solid hemispherical part of this, with a flat surface on which people live (Nussbaum, 1985).



From earth, Sandra sees stars in the direction of the moon, but astronauts see the stars either side of their craft from their viewing ports. Sandra concludes that the spacecraft passes the stars on the way to the moon.

However, the stars are so far away that they would appear to be in the same direction from the spacecraft as from the earth…the stars seen to be to the side of the craft, are not the ones Sandra sees 'near' the moon.

Sandra does not appreciate that stars seen to the side of the spacecraft, would appear in the same direction from earth…

and stars seen to be in the direction of the moon from the earth, also appear to be in that direction from the spacecraft

Figure 1: Interpreting Sandra's alternative conception of space

Despite commonly being taught about the seasons (often a topic met at the top of primary school in the UK), it remains common for students to suggest that the earth is closest to the sun when it is Summer – exactly who's Summer is not usually considered.

There is also a common alternative conception that there is no gravity on the moon *because* there is no air there (with the implication gravity needs air as a medium), whereas the scientific model suggests that the gravitational field strength at the moon's surface is too low to retain an atmosphere. Interestingly, this conception appears to be seen by students as quite consistent with images of people walking, jumping and driving buggies on the moon. The increased span of a step on the moon seems to be seen as some kind of floating, apparently drawing upon an intuitive 'belief' that even without gravity things will eventually ('naturally') end up back on the ground.

It is well recognised that many alternative conceptions found amongst learners reflect, at least superficially, ideas that were once respectable among scientists or their predecessors (Piaget & Garcia, 1989), and it is of note that this particular conception reflects some of the contemporary concerns about Newton proposing gravity as some kind of occult force acting at a distance.

The most common class of alternative conception about force and motion was mentioned in an earlier section, and these ideas are often labelled 'impetus' thinking and considered to be akin to Aristotle's ideas about dynamics (Gilbert & Zylbersztajn, 1985), albeit lacking the sophistication of Aristotle's own model (Toulmin & Goodfield, 1962/1999). It was suggested above that this conception is found to be highly intuitive, and resistant to teaching.

It can also be the case that even when a Newtonian framework for understanding linear motion is acquired, the physics of circular motion – to which orbital motion commonly approximates – may still be problematic. This can be illustrated in relation to Alice, whom I talked to when she was a student studying university entrance level courses in an English sixth form college. I asked Alive about a range of physics and chemistry topics, looking in particular to explore the level of coherence between her thinking in different topics (Taber, 2008a). Alice had learnt the basic principles inherent in Newton's laws of motion and applied ideas about unbalanced forces being a cause of motion, and specifically acceleration, in a number of situations – falling apples, parachutists etc. She described how increasing air resistance on a parachutist would lead to balanced forces and so a terminal velocity. Although Alice correctly identified unbalanced forces with acceleration, she considered orbital motion to be the result of balancing centripetal and centrifugal forces, that kept the orbiting body moving round. Alice described velocity as speed with a direction, but acceleration as a change *in speed*, and so she did not seem to consider a change of direction alone as sufficient criterion for an acceleration. Although Alice seemed to have a reasonable understanding of balanced and unbalanced forces, and applied this idea across a range of contexts, she misapplied the principle in the context of orbital motion.

Here she demonstrated another common alternative conception, considering circular motion as being the result of balanced forces. She thought that the planets were subject to a balance between "centripetal force … keeping something in an orbit, but also the forces opposing that, which I think is centrifugal…which would send it out of orbit". This seemed to be a misconception of *the status* of circular motion, rather than any difficulty in analysing the situation. In her thinking, orbital motion was *not* accelerated, and so was ontologically similar to linear motion (cf. McCloskey, Carmazza, & Green, 1980).

These brief examples offer just a flavour of the difficulties students find with understanding what we might think of as quite fundamental aspects of space science. Space is huge, such that travel to even the nearest stellar neighbours to our own system would involve very long journeys, even if close-to-light-speed travel becomes possible. Yet in familiar science fiction, moving between worlds inhabited by intelligent beings (usually bipeds, with bilateral symmetry, between 1 and 2 metres high) is commonplace. The universe has evolved over periods of time quite beyond human comprehension in anything other than a formal sense, so that a sense of the relative magnitude of the blip that is human kind is again not something we can readily appreciate. Indeed one study of secondary students' thinking about astronomy concluded that "students' ideas in astronomy are a hybrid of hearsay and imagination, with some tension between the two" (Riga, 2008: 1).

Learning about the evolution of living things

Perhaps at least as challenging as understanding about the physical structure and evolution of the universe, is learning about evolution of its biota. This of course, is a key topic for many of those concerned with the 'science wars' due to the vociferous campaigns by those objecting to the teaching of evolution in schools, or at least claiming that as it is 'just a theory' it should be taught as part of a 'balanced' approach. (In science, an established theory has high status, but those lacking understanding of the nature of science often see a theory as little more than a guess which has not yet been proved.) This usually means also teaching about biblical creation myths as if historical accounts, or at least presenting 'intelligent design' (ID) as an alternative 'theory' on par with natural selection. Rodrigues and Carrapiço (2006: R-4) argue that as "ID advocates explain that the specified complexity that exists in biological organisms can only be explained by being designed by an intelligent agent", then its proponents consider "astrobiology a danger for its policies, dogmas and philosophy".

This is a complex and nuanced debate, which may sometimes be obscured by some of the rhetoric that the topic attracts. Certainly among professional biologists, there is very little doubt (a) that evolution did occur, and (b) that the Darwin-Wallace mechanism of natural selection (Darwin & Wallace, 1858) is a key part of the scientific explanation of how evolutions occurs.

As a personal aside, I am writing this Chapter whilst working in the University where Darwin took his degree, at a time when we are especially celebrating his work: 2009 is Cambridge University's 800th anniversary, which coincides with the 200th anniversary of Darwin's own birth, as well as 150 years since the publication of his *On the origin of species* (Darwin, 1859/1968). It seems opportune, then, to point out that whilst it is commonly claimed that Darwin's (and Wallace's) central idea was simple (Dawkins, 1988), this rather underplays the intellectual achievement. Leaving aside his understandable ignorance about what genes might actually be, Darwin's explanation for the origin of life actually requires the coordination of a range of different ideas that have to all be understood, and then coordinated into a single explanation, before the principle of natural selection becomes 'simple' (Taber, 2009a). Evolution is one of the most demanding ideas we ask school children to learn, certainly in biology, and probably across science. Indeed, even within biology, there is on-going debate about the precise nature of evolution - not at the level of doubting natural selection takes place, but certainly concerning the precise way it should be understood at the level of genes, organisms, populations and species (Eldredge, 1995).

Consider how some of the participants in the *Understanding Science Project* explained evolution to me. Amy, Jilly and Mandy were nearing the end of their compulsory schooling (at the end of their penultimate year, aged 15), and had been studying the topic for the English school leaving examinations (the General Certificate of Secondary Education):

> "[Evolution is] kind of animals or plants or humans or whatever, like kind of, erm, well, evolving, …yeah, to kind of like adapt to their surroundings and stuff.…
>
> We were doing this bit on Charles Darwin when he was studying finches in an island somewhere, and he found that like on neighbouring islands that the finches all had different shape beaks because of erm the type of food that was there, so they'd kind of evolved to like suit their surroundings.… like over a long time they've kind of changed in like – erm to kind of like make life easier (or something)."
>
> Amy, 15 year-old

> "[Evolution is] like developing things…living things. It's kind of like mutation, it's like when you've got one thing like, and then it's like – gives birth and there's

> something, I wouldn't say wrong, but different about it, and then somebody else would maybe have something different, and then they'd kind of breed … and you'd have this whole new species this kind of like slight mutation.
>
> [For example] that's the whole thing about the chicken and the egg, isn't it? There's supposed to be something that's nearly a chicken, laid an egg, and it actually was a chicken, so the egg came first, because the egg was laid by something that was nearly a chicken but not quite, and then, the little egg was kind of mutated, so.
>
> [We know this] because there wasn't always humans was there, there was only like kind of little tadpoles swimming about, and they kind of evolved into us… because things aren't always the same… there are like records of things, and then there's not exactly the same things, anymore, they're different… it's really gradual…cause it's like that Charles Darwin person, he went to loads of islands, and he looked at different birds, and some of them had little hard beaks, because all they had to eat was nuts, and some of them had really long beaks, because they had to fish in like really deep flowers to get the nectar out. And so, that's something to do with it."
>
> Jilly, 15 year-old
>
> "[Evolution is] how animals get the way they are, it's – the strongest, like the survival of the fittest, kind of thing …there's an example I saw in a book, and it's like giraffes may have started off with really short necks, so they would have got all the like horrible leaves at the bottom of the trees, and then a couple would be born with longer necks so they would be able to get the nicer more nutritious leaves at the top, and so … if they mated, then they could have more [offspring] with longer necks, and then the leaves would be, just the shorter ones would die out, 'cause – there wouldn't really be any leaves.
>
> [Human being evolved from] like, erm, monkeys and primates, but in the theories, everyone started from a single – celled thing…I suppose it's logical, because if you - I don't know, 'cause erm Charles Darwin, he kind of thought of this idea, he studied finches, on some islands, and he noticed that the different finches had different shape beaks on certain islands, and he thought there had to be one finch to start off with, or two finches, and then when they had children, they went off to different islands, and depending on the food, they got different types of beaks … he probably did lots more research as well."
>
> Mandy, 15 year-old

Amy, Jilly and Mandy were all conscientious students, who had elected to take extra science as part of their secondary school course (they were studying 'triple science', whereas the majority of students in the UK only study the standard 'double science' – a broad and balanced science course considered equivalent to two school subjects in the school leaving examinations). All three were quite happy to accept evolution, and all had picked up some general ideas about the topic. They all accepted the variation in finch beaks that Darwin observed at the Galapagos as evidence for evolution, although in itself this is at best suggestive and hardly conclusive. It certainly does not provide a convincing case that all living things evolved from single celled organisms, as Mandy suggests. Jilly accepts the fossil record as evidence, but apparently on trust without knowing any details. She talks about mutations, but without any notion of how selection might act on mutations: her account seems more in line with totally random changes that just happen to lead to present life forms. Mandy reports the giraffe example, apparently misconstruing why reaching higher leaves would even be an advantage, but does not make explicit that for this narrative to 'work' one has to accept both that initially some giraffes would be born with longer necks (without having long-necked parents), and that this characteristic can then be passed on through sexual selection.

I am certainly not looking to criticise these students. They had experienced limited instruction in a topic that was just one of many they had to study on their course, and they all seemed to have acquired something of the gist of the topic. Indeed, sadly, they were likely studying effectively if their aim was to develop sufficient understanding to pass their school examinations. Moreover, like most students in the UK, they had no strong reasons to question this bit of science, and so accepted the arguments with as much (that is, as little) critique as if they had been learning about how the electrical bell works or how ammonia is made industrially.

In some ways it is disappointing that students are so easy persuaded by the authority of science teachers and textbooks, but when evolution is not seen as contentious then this level of understanding is probably a good enough base for developing a more nuanced understanding if the topic is later studied at a higher level (and all three of these girls did opt to study biology or human biology further after reaching the school leaving age). And of course their 'faith' in science teaching was justified: evolution by natural selection is a well supported theory: as Mandy had correctly assumed, Darwin did indeed do "lots more research as well" before asking us to accept natural selection.

But not all students come to science open to accepting ideas about evolution. In the UK context only a small proportion of school children come from 'fundamentalist' religious backgrounds that reject evolution. However, that may not fully reflect the potential magnitude of the issue. A small-scale study with 13-14 years olds from four diverse English schools for the *Learning about Science and Religion* project , suggested that some school children see scientific teaching about evolution as contrary to their faith because it seems inconsistent with the stories in Genesis 1 and 2, *even when* they attend mainstream Christian churches (such as Anglican or Roman Catholic churches) that fully accept the scientific accounts of evolution (Taber, 2009b). These pupils seem to just *assume* that they are meant to take the Genesis stories literally, even though that is not actually part of their faith tradition. This is of concern, especially when in some other countries (including the USA), significant proportions of students will come from backgrounds where evolution is actually denied by their faith leaders.

If the level of understanding developed by most secondary school children is similar to that displayed by Amy, Jilly and Mandy (and of course, generalisation from a few cases in one school should not be assumed) then it hardly provides a robust appreciation of the strength of the scientific case for natural selection. Although that scientific case is extremely well supported, without understanding all the links in the argument, nor actually being exposed in some detail to the wide range of evidence, it is clear that school children who have a Worldview inconsistent with evolution are hardly likely to be persuaded to accept the scientific model (Taber, 2009a). This has to be of concern when if there is one scientific theory which more than any other needs to be appreciated to make sense of astrobiology, it is surely natural selection.

Conclusion

The central argument of this chapter has been that if scientists working in astrobiology genuinely want to develop public understanding of their field, then they need to consider moving beyond the notion of 'science communication' and appreciate the challenges faced by professional practitioners of science education. The 'bad news' in this regard is (a) that we know that it can sometimes be very hard to bring about conceptual change when learners have strong preconceptions of a topic, and (b) that when we consider the pre-requisite knowledge for understanding new discoveries in astrobiology, the existing research in science education suggests we are dealing with topics where there are great learning difficulties. Some of the key points highlighted have been that:-

- People generally do not understand the basic mechanics of linear, let alone orbital, motion even after being taught the topic in school;
- There are common alternative conceptions about the 'structure' of the universe, which little appreciation of the nature of different types of bodies and limited appreciation of the vastness of scale (in terms of space or time);
- School teaching tends to leave pupils with a dubious understanding of why chemical reactions (a key feature of appreciating the science of the formation and evolution of life) occur;

- Evolution by natural selection is too complex a theory to be readily understood by most school children – although the basic components may be within students' grasp, coordinating them into a coherent model is demanding, and will not be achieved without studying the topic over time, in some depth.

In addition to all this, we also know that within popular culture there are common ideas and perceptions which are likely to distort any new learning in this area: perceptions of 'alien' life are heavily biased towards intelligent humanoid beings; even many people in the USA do not believe that information about the space programme is always true and reliable (i.e. the belief that the moon-landings were a 'hoax'); and many people have a worldview that excludes accepting that life on earth could actually have evolved - a rather major consideration for a science with such a strong focus on how life evolves.

There are clearly major challenges here. However, there are some positive factors that should also be borne in mind. Even if the public tends to see life beyond earth in a rather distorted way, there remains a very strong interest in the issue. The aliens of popular fiction, and even the fascination with UFOs and the associated conspiracy theories, at least provide a strong motivation to learn about space that is found among few other areas of science outside of medicine. Attempts to build extra-mural courses around astrobiology have been reported to have been successful in both informing members of the public, and enthusing them into advocates for science (Brake, Griffiths, Hook, & Harris, 2006). This should at least be reassuring for scientists attempting to compete with the extraordinary claims of much pseudoscience. For as Carl Sagan (1995) warned, "If you are awash in lost continents and channeling and UFOs and all the long litany of claims so well exposed in the Skeptical Inquirer, you may not have intellectual room for the findings of science. You're sated with wonder."

It has been suggested that the inter-disciplinary nature of astrobiology - described by Cockell (2002: 265) as a "retreat into an inter-disciplinary milieu in the face of questions that perplex us" - makes it an excellent context for helping people understand the nature of science (Oliveira, 2008; Rodrigues & Carrapiço, 2005), and for "the development of more holistic learning and contributing to the flexibility of the students' mental structure" (Rodrigues & Carrapiço, 2006: R-2). Indeed it has been argued that,

> "Astrobiology provides an ideal forum in which to discuss questions relating to the public and cultural placement of science. Astrobiology is a rewarding study of the boundaries between science, art, religion, philosophy and pseudoscience, and

> also acts as a measure of the dialectic between our advancing human knowledge and that which remains undiscovered."
>
> (Brake et al., 2006: 320)

The conclusions to be drawn then from this discussion of the public understanding of astrobiology then would be:

1. There are good reasons for scientists to engage with the public and seek to inform people about their professional work;
2. However, the notion of science 'communication' may underplay the very real difficulties of brining about conceptual change in science, as revealed in a great deal of educational research;
3. Given what we know about the learning difficulties in science topics that astrobiology draws upon, the field of astrobiology presents a particular challenge for effective science communication;
4. Widespread perceptions of space and aliens from popular culture will likely distort the way much of the public understands information about astrobiology;
5. However, the strong interest in space travel and extra-terrestrial life are useful motivators that lead to much interest in the topic; and
6. Effective public education about astrobiology can potentially contribute to wider aims for the public understanding of science,
7. and in particular better appreciating the nature of science.

Taking these points together, the message to scientists working in areas of astrobiology is to indeed prioritise explaining their work to the public, but to be aware of the likely difficulty of effectively communicating the science - and so to prepare themselves for this by drawing upon the literature from science education about learning difficulties and common alternative conceptions in the pre-requisite topics, and from the on-going programme of research into how to best effect conceptual change in science (Taber, 2009a).

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