Learning For a Better World: Futures in Science Education

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‘O, I am educated
    For I have been told so –
You’d really be surprised, my dear,
    At all the things I know.

‘When I was twelve years old, I learnt
    How to add a to b,
And how the Romans say “I love”
    And when the French say “thee”.

‘And I learnt how the tundra
    Behaves up in the North
And all about the prairies
    And ships in the Firth of Forth.

‘And I was taught how Jesus
    Had come to save my soul,
And all about the Pyramids,
    And how to play in goal.

‘When I was a sweet fifteen
    I learnt about the dead,
I learnt how when an acid’s near
    A litmus paper’s red.
…
‘O yes my eyes are gentle;
    And yet my mind is quicker,
For I read eleven hours a day
    And my specs are getting thicker.

‘And though my smile is kindly
    My teeth are rotting in my head,
And though my thoughts are up aloft
    My lower half is dead.

‘O what am I becoming
    Who is so brilliant?
Shall I become quite famous?
    Sometimes I think I shan’t.

‘Sometimes I think that you, sir,
    Have killed your lovely duck,
And I shall lay no golden eggs

For you to gloat and cluck;

'I think your education
Has maimed my better half
And has blown up my other side
With cubic feet of gas. (Larkin untitled, in Burnett 2012, pp.163-5)

I have argued for a number of years that science education, as currently undertaken in schools, is generally too narrow in its conceptualisation, its aims, its curriculum, its teaching and its assessment and that this is a major reason why it fails to engage many young (Reiss 1993, 2013). The aim of this chapter is to present a unified framework for understanding the scope, the purpose and the pedagogies of science education in the settings of school, out-of-school and lifelong learning. I attempt to show how science education can be reframed in a way that is true to science, true to education and engages with and takes seriously the interests and desires of learners, of whatever age.

It is increasingly evident that school science usually does not take enough account of student diversity, particularly with regard to how students learn science, where they learn it and what they find engaging about it. Gone are the days when it was quite exciting to do an experiment in a school science lab to see that plants make starch or that copper gains in mass when it burns. Nowadays, all of us are bombarded with science stories in the media. Indeed, the opportunities to access contemporary science are almost endless. I can look digitally through telescopes that give me live views of far-off galaxies and through web-cams that show me endangered birds of prey feeding their young in real time. How can schools compete? We need to acknowledge that much of where today's young people learn about science is already not in the classroom but via such as extra-school sources as the internet, in virtual reality, science museums, science centres, television, radio, magazines, films (fictional and non-fictional) and non-school books.

This is not, of course, to imply that there is not a central place for school science lessons in the learning of science. There is an urgent need for science education, both inside and outside of schools, to recapture a vision of how we can understand the physical world and how we should wisely and considerately make use of that knowledge. Schools have three great strengths in this regard: specialised teachers of science; specialised science equipment; and, other learners of science. None of these is restricted to schools but schools are distinctive in reaching the overwhelming majority of each cohort for substantial chunks of time. They therefore have the potential to enable all learners, including those with little science capital (Archer et al. 2012) – those who are never taken to science museums or centres, who have no adult relatives or friends with any connection to science and who are not encouraged to watch programmes or to read books about science – to benefit from science teaching.

I will begin by arguing that a rigorous science education needs to start with an examination of the purpose of education and then consider the place of school education for the learning of science, given that science learning also takes place before, outside of and after schooling. I will then exemplify these general considerations with specific reference to curricula and practices in science education at a range of ages. Admittedly, separate sections on pre-school science education, primary science education, secondary science education and lifelong science education – and I haven't even covered tertiary science education – can do no more than act as pointers. Hopefully, though, they help indicate that what I am proposing is feasible yet different from what happens nowadays in most sites of science learning.

WHAT SHOULD BE THE AIM OF SCHOOL EDUCATION?

Before designing a school science curriculum, one needs to determine its aims (Reiss 2007). Immediately, one is faced with a choice – does one start with science or with education? Curricula exist in a wide range of forms and there are a number of ways in which they can be developed (cf. Kelly 2009). However, national curricula typically start with a list of subjects. They take for granted a dozen or so discrete school subjects and the knowledge they embody. It is subject requirements that get filled out. This approach has a number of consequences. For example, a subject-led curriculum, especially at secondary level, starts with, and so is necessarily constrained by, the availability of teachers capable of teaching certain subjects. More fundamentally, there is a general implicit presumption that agreement exists as to the purposes of school education without these purposes being critically examined anew.

An alternative to starting with subjects is to begin further back, with education and aims (Reiss & White 2013). To a certain extent this approach is closer to the continental European tradition of *didaktik* when it takes an approach to education based on *Bildung* – an education concerned with the formation of the whole learner through personal transformation. An aims-led curriculum has a fundamental advantage over the more usual, atomistic Anglo-Saxon approach to curriculum in that it can start with the needs and wants of students – both students as they live in schools and students once they have left their schooling behind. Another advantage of starting with aims is that if one doesn't, one finds that aims end up getting tagged on. For example, when the National Curriculum for England and Wales was first created in 1988, it had next to no aims to guide it. More recent versions have included lists of overall aims, but these have been tacked on to a structure already in place. Crucially, they do not generate that structure. John White and I have argued that that there are two fundamental aims of school education, namely to enable each learner to lead a life that is personally flourishing and to help others to do so too (Reiss & White 2013).

What constitutes a flourishing life?

The notion that humans should lead flourishing lives is among the oldest of moral principles, one that is emphasised, for instance, by Aristotle in his 'Nicomachean Ethics'. There are many accounts as to what precisely constitutes a flourishing life. A hedonist sees it in terms of maximising pleasurable feelings and minimising painful ones. More everyday perspectives may tie it to wealth, fame, consumption or, more generally, satisfying one's major desires, whatever these may be. There are difficulties with all these accounts. Pleasure maximisation sounds great but provides a somewhat narrow conception of what it is to be human – cf. J. S. Mill's famous "it is better to be a human being dissatisfied than a pig satisfied; better to be Socrates dissatisfied than a fool satisfied". A problem with desire satisfaction as the sole arbiter is that it allows ways of life that most of us, for all that we value autonomy, would deny were flourishing, lives devoted to collecting milk bottles or viewing pornography, for instance.

A life filled with whole-hearted and successful involvement in a range of more worthwhile pursuits – such things as significant relationships, meaningful work, helping at a nature reserve, gardening, cooking, watching excellent films, being a member of an organisation that pursues worthwhile ends – is on a different plane. Most of us would consider that to be fulfilling. At the same time, nearly all of us in a modern society like our own presume it is largely up to each of us to choose the mix of relationships and activities that best suits us (certain family obligations are generally excepted from this generalisation, though less so than in the past).

A central aim of the school should therefore be to prepare students through their lessons and other activities for a life of autonomous, whole-hearted and successful engagement in worthwhile relationships, activities and experiences. With many of these – cooperative work activity, friendships and enjoying literature, for instance – it makes good sense to see that students gain first-hand experience. For others – things like mountaineering, composing symphonies, choosing to live an unmarried life, running a multinational company, walking on the Moon – imagined rather than direct involvement is likely to be more appropriate. This aim also involves acquainting students with a wide range of possible options from which to choose. With their development towards autonomous adulthood in mind, schools should provide students with increasing opportunities to choose among the pursuits that best suit them. Young children are likely to need greater guidance from their teachers, just as they do from their parents. Part of the function of schooling, and indeed parenting, is to prepare children for the time when they will need to, and be able to, make decisions more independently.

Equipping every student to help others to lead personally fulfilling lives

We want people to want other people, as well as themselves, to lead fulfilling lives. Such an aim is found in a range of moral philosophies, both religious and secular. Negatively, this means things like not hurting other people, not lying to them, not breaking one's word. Positively, it means helping others to reach their goals, respecting their autonomy and being fair, friendly and cooperative in one's dealings with them. Schools can reinforce and extend what parents and others in families do in developing morality in young people. Schools can widen students' moral sensitivity beyond the domestic circle to those in other communities, locally, nationally and globally. They can also help them to think about moral conflicts in their own lives and in those wider spheres. They can encourage students to reflect on the basis of morality, including whether this is religious or non-religious, rooted in human nature (Ridley 1996) or an invention of society (Mackie 1977). There can be a danger that this second aim can become nationalistic or be abused in a totalitarian state but good education can at least reduce the likelihood of this happening by encouraging students to develop the skills and disposition to be critical.

As future citizens, the great majority of students will contribute to the general wellbeing, as well as to their own, through work they undertake primarily after they have left full-time education. This activity will often be remunerated, though much of it, e.g. caring for children or elderly relatives, may not be. As autonomous beings, students will eventually have to make choices about what kind of work to engage in. Schools should be helping them in this decision-making by developing their awareness of a wide range of vocational possibilities and routes into them, as well as their advantages and disadvantages.

Broad background understanding

There is an important link between the two major aims. Whatever we do in our lives that brings us personal benefit, or is intended to benefit others, takes place against a broad background of thoughts about the world we live in. Closest to home are thoughts about what sort of beings we are. We all grow up to believe, for instance, that our individual lives are finite, that we may or may not stay healthy, that the future has a considerable element of unpredictability (see Buntting & Jones, this volume). We all, bar sociopaths, come to see our lives as inextricably and positively bound up with the lives of other human beings. These perceptions cannot but influence the way we lead our lives.

Part of the task of education—at home and at school—is to help students to form this background that will colour everything they do. At a fundamental level, some of us will live by religious or other beliefs that give us answers to the deep questions, while others will live without such beliefs. But much of the background is less contested. Indeed, much of it will consist of well-founded scientific conclusions – about, for instance, the building blocks of life, our part in the ecology of nature and the social nature of humanity. This leads into the second part of this chapter, where I explore what an aims-based approach to curriculum design might mean for education about the sciences in school. I begin by reviewing current attempts to formulate aims for school science education.

CURRENT ATTEMPTS TO FORMULATE AIMS FOR SCHOOL SCIENCE EDUCATION

Many aims for school science education have been proposed (Reiss 2007; see Fensham, this volume), though these are often implicit. A frequent aim of science courses has been to provide a preparatory education for the small proportion of individuals who will become future scientists (in the commonly understood sense as employed professionals). This aim has been widely critiqued on democratic grounds (e.g. Millar & Osborne 1998). After all, what of the great majority of school students who will not become such scientists?

Another aim is to enable ‘scientific literacy’. Although there has been a long-running debate as to the meaning of the term (e.g. Miller 1983), generally, scientific literacy is seen as a vehicle to help tomorrow’s adults to understand scientific issues (Gräber & Bolte 1997). The basic notion is that science education should aim to enhance understanding of key ideas about the nature and practice of science as well as some of the central conclusions reached by science. Perhaps to be included within this category is the argument that to be an educated person in the 21st Century is to understand something of science (e.g. Shamos 1995). This is the ‘science as culture’ argument; that science is as worth studying in itself, as are, for example, literature and the arts.

A further aim is that many science courses hope that as a result of what is learned, pupils both now and in the future, as adults, will be able to gain practical benefit from it. At its most straightforward this might be by entering paid employment that draws on what they have learned in science. Although, as noted above, most students do not enter such careers they too may still benefit individually from school science. For example, in most science courses, in countries round the world, it has long been accepted that one of the justifications for the inclusion of certain topics is that knowledge and understanding of them can promote human health. Such topics may include infectious diseases, diet, reproduction and contraception, exercise and the use of drugs (including smoking and alcohol).

Another, more mundane, way in which school science might help individual advancement is by providing what I have termed ‘science education for consumerism’ (Reiss 2007). This is the hope that school science education might, for example, help us choose the most appropriate technological goods (is it worth me paying x% more for a washing machine that uses y% less hot water?) or make broad decisions, for instance about climate change, on narrow criteria (where should I purchase my second home to minimise problems with rising sea levels or extreme weather events?). This is a sub-set of the more general and long-established argument that science education should be for public understanding (American Association for the Advancement of Science 1990; Millar 1996).

A further aim of school science education is that it should be for citizenship (Jenkins, 1999). A 'weak' version of this approach consists of learning what a democracy is and the place that science plays in being an engaged citizen. A 'strong' version entails using such knowledge to bring about desirable change. This latter philosophy is closely allied to claims that the aim of school science education should be to effect social justice or socio-political action (e.g. Calabrese Barton 2001; Carter 2005; Hodson 2009). Calabrese Barton draws on feminist approaches to show that many of the students with whom she and her colleagues work, whilst seen in school as poor attainers in science, are actually perfectly capable of high quality science work provided they are given real choice in the science they work at.

It is evident that there are currently diverse aims for school science education. It is important, though, to emphasise that most teaching of school science proceeds on the assumption that such knowledge is good for students, without the precise aims having been thought through with any rigour and without the science curriculum beginning from such aims. Instead, science curricula generally begin with science. It might be thought that this is a sensible starting point but it leads all too often to disengagement as many students fail to understand the point of what they are learning (Reiss 2000; Schreiner 2006). I now outline how an aims-based approach to the curriculum that takes the notion of human flourishing as its core value might inform science education. Some might consider such an idea to be utopian; others that it is not sufficiently radical. As an evolutionary biologist I have a great belief in change but see change as most likely to result in sustained improvements when it is implemented incrementally. We can start with existing curricula and shift them appropriately. In any event, what is generally most important is how teachers teach. We want science teachers, whatever the ages of their students, to have a passion for science and a passion for education. Learners are often capable of more than their teachers presume.

PRE-SCHOOL SCIENCE EDUCATION

Relatively little has been written about pre-school science education despite the importance this period clearly has for how each of us comes to understand the world. Nevertheless, there is growing interest in early years/emergent science, including a journal published since 2011: *Journal of Emergent Science*. A problem that bedevils many attempts to devise curricula for this age range (approximately 2-4 years) is that all too often such curricula are over-influenced by curricula for primary-aged children. Indeed, this is a common problem in education – that education for phase n is largely seen as preparation for phase n+1. This approach results in a pernicious trickle-down effect where curricula for young children are partly determined by the needs of undergraduates.

So what might we want pre-school science education to seek to develop in young children? For one thing, we might want children to be encouraged to observe carefully and to explore what they see (Johnston 2011). The skill of observation is of value for a range of subjects beyond science, of course, but it is a key skill within science. Actually, the first time I can remember being encouraged to observe carefully in science was in a first year undergraduate practical session where we were undertaking a dissection of an unfamiliar fish (the head of a cod, from memory). The whole point of the exercise was that there was no textbook – unlike the drawings we did at school of histological specimens where our drawings were heavily influenced by the plates in such books as Bracegirdle and Miles (1971). For the first time in my life, so far as I can recall, I spent a sustained period of time observing carefully what was in front of me. While I have always considered myself 'bad at drawing', to my surprise, I found that my drawing of the bones of the head was rather better than my previous efforts at anatomical drawing.

Observation is closely aligned to listening, and at this age children can be encouraged to listen carefully and to develop (perhaps it is better to write 'retain') their ability to distinguish between sounds of similar pitch. The sorts of environmental education games where one closes one's eyes, or is blindfolded, and then attempts to locate the source of a sound without being heard oneself can make such learning enjoyable and personally challenging.

One would want children too to develop their scientific vocabulary. At this age, of course, such vocabulary is not specific to science and nouns like plant (to be distinguished from flower), water and ice, adjectives like heavy, light (in both its main senses) and dark, and prepositions like above, below, beside, near and far can all be learned or have their meaning refined or rehearsed.

At this age, above all, one would want learning about science to be closely connected to a child's family. One of the great problems with science, unlike, say, reading, is how high a proportion of parents, despite the efforts of occasional projects such as SHIPS (School Home Investigations in Primary Science) (Solomon & Lee 1993) presume that they can't undertake it with their children. Good preschool science education can not only help young children in their learning but encourage parents to believe that they have a positive role to play.

Above all, one would want a child to begin to realise that s/he can playfully explore (interrogate) the material world. Objects differ in a whole range of observable features: their feel, their smell, the extent to which they keep their shape and so on. Such features can be investigated and begin to be related to the uses of the objects. Teachers should listen to the questions that pre-school children ask, whether such questions are asked in words or actions.

PRIMARY SCIENCE EDUCATION

Until the 1960s, primary science in schools hardly existed other than as natural history or nature study. Since then, primary science has taken off across the world. Despite, though, the large amount that is written about primary science, insufficient theorisation has yet been undertaken as to what should be taught in primary science. This issue is particularly important as in practically every country only a very small minority of teachers of primary science have deep subject knowledge of science. There is therefore a real danger that certain topics (e.g. forces, the phases of the Moon) are taught when the teachers themselves have substantial misconceptions about them.

This is neither to denigrate primary science teachers nor to imply that teachers, whatever the age of their students, must have perfect knowledge. But we know, for instance, that quite a high proportion of physics graduates find it difficult consistently to apply Newton's first (If there is no net force on an object, then it continues in a straight line at constant speed) and third (When a first body exerts a force F1 on a second body, the second body simultaneously exerts a force F2 on the first body equal to -F1) laws of motion, let alone truly to have internalised them (diSessa 1993). Such teaching is surely better left to secondary school when: (a) students are more likely to be taught by specialist physics teachers; (b) students are more likely to be able to cope with the abstract reasoning that is either required for understanding such topics or, at the very least, greatly facilitates such understanding (cf. Shayer & Adey 1981).

Related to this issue is the problem of putting into the primary curriculum material that is better left to the secondary curriculum because of the availability there of more specialised equipment. In England and Wales, we have recently completed a rather bruising experience in which a new National Curriculum has been devised, in many ways the most substantial revision since the original National Curriculum was introduced in 1989. A pre-occupation of the government that England must have the best education system in the world led in the initial drafts, drawn up by civil servants with little or no experience of school teaching, to a principle in which any topic that featured in a world-leading jurisdiction (as defined by its position in PISA league tables) at age x had to appear in England at age x or earlier.

This resulted, for example, in an initial requirement that Year 6 pupils (10-11 year-olds, still at primary school) should know about sub-cellular components. The only way this knowledge could be learned in most primary schools, that generally lack classroom sets of high quality microscopes, would be from textbooks, computer simulations, videos or suchlike. Valuable as all these are for learning in science, there is little to beat being taught, as students routinely are early in secondary school, how to use a microscope with a range of objective lenses so that one can see for oneself such organelles as the nucleus and chloroplasts. Fortunately, the science and science education communities put on a relatively united front and the final version of the National Curriculum, while far from ideal, at least had such problems ironed out.

More positively, primary science can build on and challenge children's developing understandings of the scientific world, that is, it can help children develop their skills of enquiry (e.g. Rinke et al. 2013) and it can begin to help children understand some of the Big Ideas of science (Harlen 2010 2011). Most primary schools do not have school laboratories and this can be a great asset. Rather than striving for a watered-down version of secondary science, teachers of primary science can help pupils connect what they are learning about science in the classroom with what goes on outside of school (see Rennie, this volume), whether in everyday situations, for instance in the home or a park, or in specialised settings such as a science centre or a nature reserve. An advantage primary teachers have is that they typically teach a wide range of subjects. They can therefore help children to see how science skills and knowledge can be of value in other school subjects, just as they can help children see how skills and knowledge learnt in other school subjects can be of value in science.

SECONDARY SCIENCE EDUCATION

The five or so years of secondary schooling (round about years 7 to 11 in many countries) are a crucial phase of school science education. How does a focus on flourishing shape the curriculum and pedagogy at this stage? I will concentrate here on two considerations: first, the world of work; secondly, diversity among people.

The world of work

In many countries one of the arguments for according science a major place in the secondary school curriculum is its importance for modern society, including the world of work. STEM (science, technology, engineering and mathematics) graduates typically enjoy above average salaries and it seems to be the endless lament of Western governments that we aren't producing enough university STEM graduates (European Commission 2004; National Academy of Sciences 2007).

How, though, should one decide, for such possible employment purposes, how much and what sort of science students should experience when at school? The first principle, surely, should be to provide sufficient material for students to be reasonably well informed when deciding whether or not to continue with the subject for career reasons once it becomes optional. This principle does not point to a science curriculum providing comprehensive coverage; science teaching could include, among other things, what John White and I have referred to as 'taster-option' courses (Reiss & White 2013). Furthermore, a significant proportion of this material should be 'applied' so as to indicate the uses to which such knowledge is put. Indeed, not only should it be applied but courses should indicate how people make use of it in employment.

To give just one example, when teaching the topic of plant nutrition (sadly, not a topic that many students presently find that interesting), one might start by looking at how an arable farmer decides how much, if any, fertiliser to apply and when (which depends on such things as the stage of crop growth and the weather). This approach would soon get into issues about organic and small-scale as opposed to agrochemical farming, the economics of farming and the values people attach to their food as well as to more mainstream scientific matters such as the absorption of minerals by plants, the transport of such minerals in the xylem and their use in the synthesis of organic compounds.

However, despite attempts to introduce more applied material into a number of science courses, such material, and not only in science courses, is often considered of lower intellectual worth than ‘pure’ knowledge (Pring et al. 2009). Such an attitude, aside from being narrow-minded, is probably counterproductive; some students are attracted by learning material that they can see might lead to satisfying employment. In any event, the relationship between pure and applied science is not simply one-way, in that pure knowledge leads to applied knowledge. As historians and sociologists of science now accept, the relationship is more complicated than that. In some cases, advances in the applied sciences lead to advances in pure sciences (Gardner 1994).

Diversity among people

People differ from one another greatly. And yet, from school science, one might think we are all the same bar our age, the fact that some of us are male and others female and some of us have medical conditions, such as cystic fibrosis or sickle-cell anaemia, or other natural variations, such as blue eyes or attached ear lobes, that result from single gene variants.

The reality, of course, is that humans of a given age vary greatly for reasons to do with inheritance, our upbringing, the environments in which we find or place ourselves, the interactions between our inheritance and these environments, our choices and chance. In ignoring most human variation and the reasons for it, school science curricula give the impression that such differences are uninteresting (which they aren’t), unimportant (which they aren’t) or too difficult for school study – which they generally aren’t and, anyway, school science education should serve as an introduction to interesting and important issues; as the next section of this chapter emphasises, science education doesn’t cease when students leave school.

In some cases, I suspect that school science curricula fail to deal with issues where diversity exists – for instance, human intelligence – because of a fear that raising such matters may cause problems. However, not raising them is likely to cause more problems. I suspect that students, for example, are more likely to believe that intelligence differs between men and women or between ‘races’ if they have not been taught critically to examine what is meant by intelligence and how it may be measured and used. One reason why teachers may be reluctant to include such material in the classroom is that the pedagogy required may be unfamiliar to them. However, teachers can learn to teach in ways that take serious account of socio-cultural issues, especially if they are convinced of the value of such teaching for their students. Another reason for teacher reluctance is that such teaching may require up-to-date content knowledge. There are many ways of dealing with this issue, including time for professional development and 'flipping' the science classroom so that the teacher is not seen as the reservoir of all knowledge – a change that makes all the more sense given the increasing use of digital technologies by students (see Selwyn & Cooper, this volume).

For a final example, consider how human sex is usually taught in school biology. It is dealt with as being entirely unproblematic: females are XX, males are XY, period. The reality is rather more complicated – and a lot more interesting. Sex cannot always be reduced to chromosomes. More and more students know about transgender issues and intersexuality is more common than generally supposed. Perhaps the simplest approach for biology teaching is to see maleness and femaleness as lying on a continuum (Scholer 2002; Reiss 2005). Done well, such teaching can provide students with a better scientific understanding of the roles of chromosomes, hormones and the environment in the determination (rather, underdetermination) of ourselves. It can also help considerably to aid human flourishing.

LIFELONG SCIENCE EDUCATION

In many ways the implicit assumption of school science curricula seems to be that once you have left school your science education ends unless you continue, for example at university, to take conventional courses in one or more of the sciences. And yet this is surely not an assumption made of curricula in English, in music, in the arts and in modern foreign languages. Here there seems to be more of a belief that the role of schooling is to prepare each of us for further study in these subjects. One studies *Jane Eyre*, *Lord of the Flies*, *The Rime of the Ancient Mariner* and *The Waste Land* at school in England in the hope that one will be inspired to read novels and poetry for the rest of one's life.

The reality, of course, is that out-of-school experiences have always been important for learning about science and they have never been more important than nowadays. There has been a veritable explosion in the media through which science can be learned (Fenichel & Schweingruber 2010). Interestingly too, disciplines, such as history, that once had rather distinct methods for establishing their knowledge claims are increasingly drawing on science to establish what happened. To give just one example, analysis of the teeth of the majority of the crew on board the *Mary Rose* reveals that they were not English, instead being of southern European origin, possibly Spanish prisoners of war or mercenaries (Ghost of the Mary Rose 2008). This discovery raises the possibility that the distinctive failure to close the gun ports when the ship made a sharp turn in a battle with the French in July 1545 may have been because many of the crew did not understand orders given to them which might also explain the final words of the ship's commander, Admiral George Carew, that his men were "knaves I cannot rule". Archaeology is an example of a discipline that is being revolutionised by the application of science.

But there is more to lifelong learning than learning accepted science. More and more people are contributing to science. In some cases such contributions sit outside mainstream science. Creationist science is an obvious example but so too is what can be termed 'Outsider Science' (à la Outsider Art). Many people seek meaning in their lives and use science to help construct a world that makes sense to them and helps answer their questions, whether practical or existential. As I write this, there is a wonderful exhibition on in London at the Hayward Gallery called *The Alternative Guide to the Universe* (Rugoff 2013). Here, for example, we find Philip Blackmarr's drawings which communicate his theory that matter is made up from minute octahedrons that, when fitted together, model the properties of protons, neutrons and other subatomic particles. Here, too, we find James Carter's life work *The Other Theory of Physics* in which, *inter alia*, he argues that gravity does not exist. Instead, matter expands infinitely. Thus, an apple does not fall to the earth; the earth rises up to meet it. (For further examples of fringe physics, see examples on the internet or Wertheim 2011.)

However, many of the contributions made to science by adults and others outside of school accord with mainstream science. Actually, many disciplines such as astronomy, botanical recording, entomology, ornithology and palaeontology have long relied on amateur scientists to locate and identify objects. While it might be thought that the increasing professionalisation of science would have rendered such help obsolete, it has not been the case. Indeed, new technologies, not to mention the insatiable demands of science, far beyond the capacities of even the present expanding professional cadre, mean that today's amateurs are as important as ever. Hence the rise of 'citizen science', which enables members of the public to engage in real science, for example by searching for astronomical objects, identifying organisms in local environments and tracking phonological responses to climate change. Hence, too, the increasing realisation by many funding bodies, for example medical charities, that the quality of the research undertaken by professional scientists can be markedly enhanced by taking seriously the interests and contributions of knowledgeable amateurs. As yet, though, school science seems to be taking virtually no notice of such developments.

CONCLUSION

Science never stands still. Its very nature is to question and advance. School science, though, too often appears as a living fossil. If we want today's and future generations of school learners to engage with science and retain a lifelong interest in it, we will need to reform school science so that it is true both to science and to education and so that school science is seen by learners to be relevant to who they want to be, to their developing identities. My contention is that a school science that takes flourishing and student diversity seriously can contribute to this change. If students are to wish to continue to choose to study science once it is no longer compulsory, they need to find a meaningful connection between the world of science and their own interests (Rodd et al. in press).

School science education needs to be open to new ways of learning. For many, the promise that new technologies will transform learning in schools has proved to be hype (Selwyn 2011). And yet we are still in the early days of these new technologies. New technologies will change how science is learned, and have the potential to enable greater student control over their learning (e.g. Hole-in-the-Wall 2009). Pedagogies, too, need to change. After all, it is well established in many countries that it is school science education, not science, that many learners are rejecting (Bøe et al. 2011).

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