

Realising the school science curriculum

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ABSTRACT

This article identifies historical, pedagogical and epistemological problems which distance the school science curriculum from social questions, and issues of social justice more specifically. Drawing on a critical realist approach it addresses these problems and aims to demonstrate that social justice lies at the heart of inquiry and science in schools.

KEYWORDS School science curriculum; epistemology; critical realism; social justice

Introduction

Science as a subject in the school curriculum has an awkward relationship with personal, social and global issues as well as with events of clear emotional value. Compared with other school disciplines in the arts, humanities and social sciences, natural science seems removed from the questions which concern all human beings: the nature of love, the fear of death, social tensions, our relations with non-human species, suffering and happiness, right and wrong. Surveys of school students studying science (Bennett & Hogarth, 2009; Lyons, 2006; Murray & Reiss, 2005; Osborne & Collins, 2001) reflect a disaffection in the sense that they view school science as detached from their experiences as lived. That alkali metals produce hydrogen when reacted with water, that leaves possess chlorophyll and even that the force between two objects is related to their combined masses and the inverse of the square of the distance between them has little to say in any direct way about the kinds of human events mentioned above.

For a small minority of school students the patterns and problems generated by the natural and physical worlds do have a fascination to the extent that they go on to study science at university. Others pursue science in higher education for more instrumental purposes such as the increased chances of employment or vocational schemes which involve some aspect of applied science. In the latter case the Vision I science (Roberts, 2011) or academic science (Fensham, 2002) of the school curriculum often has little relevance. The vast majority of school students do not go on to study science formally after school, nor do they re-visit much of the content of school science after they have left. Lay and informal enthusiasm for science more generally, however, is prevalent with many adults, some of whom were indifferent towards science at school, and have found new insights outside the context of compulsory education (Morris, 2016; Solomon, 2013).

Critics of curriculum policy have identified this hiatus between science in school and society (Millar & Osborne, 1998). Ways in which science and technology have been perceived to be in conflict with public health and interest such as the Chernobyl and Fukushima nuclear power station explosions, Three Mile Island, food health and environmental problems, have moved in the direction of emphasising the role of science to improve public attitudes and understanding (Bodmer, 1985; House of Lords, 2000).

In fact, the relation between science, technology and society (STS) has exercised educators and curriculum policy in post-industrial economies for some years (Aikenhead, 2003; Solomon, 1988; Solomon & Aikenhead, 1994). Concerns about sustainability and environmental action have now become an explicit component of STS as STS (Pedretti & Nazir, 2011). Most school curricula in industrialised and post-industrial countries do include areas of knowledge which link science to society. *21st Century Science* which was rolled out nationally in the early 2000s in the U.K., encompassing content such as how should genetic information be used, the importance of biodiversity, improving air quality, make these links explicit (Millar, 2006). These and others such as *Perspectives on Science* (Taylor & Hunt, 2014; University of York Science Education Group, 2007) have attempted to locate scientific ideas in a broader historical, cultural and political context. The popularity of these approaches and the political support given, however, are not steady; for example

recent government policy in the U.K. has pushed back against the science-society boost of the New Labour government (Gough, 2015) in the 1990s and early 2000s. The emphasis is now on core knowledge, as an advisor to the UK government maintained: ‘We have believed that we need to keep the National Curriculum up to date with topical issues but oxidation and gravity don’t date ... we are taking it back to the core stuff.’ (<http://www.guardian.co.uk/education/2011/jun/12/climate-change-curriculum-government-adviser>).

Although the emphases on science and society in the curriculum have been subject to the vagaries of changing trends and public policy there are historical, philosophical and pedagogical aspects which play a more foundational role. I shall discuss the force of some of the arguments against science-society curriculum formulations before arguing why science and society should be incorporated into the curriculum, and more significantly, how a meaning of human freedom and social justice is integral to understanding science practise, its core concepts and its role in knowledge construction.

Society’s problem with science

In the courtyard of the British Library in London is a massive bronze statue of Isaac Newton by the sculptor Eduardo Paolozzi. It is based on a coloured print by the 18th century poet and artist, William Blake. Both Blake’s original and Paolozzi’s sculpture have an outsize version of Newton crouching over a parchment with a pair of geometric dividers. Blake’s picture is unequivocal: Newton is seen as indifferent to his primordial natural surroundings intent only on measurement. In Paolozzi’s work Newton is seen sitting on a wooden box, again measuring, but the focus is on the power of unwavering concentration. Nonetheless there is something mechanical about **Newton’s** posture as if there is a link between a deterministic universe and Newton’s laws. Blake, in common with the Romantic movement, was deeply sceptical of scientific rationality as represented by the Enlightenment, and the ‘dark satanic mills’ emerging from the Industrial Revolution destroying the beauty of the landscape. This signifies a dualism prevalent in Enlightenment thinking, that between Mind and Body, the Intellect and the Passions, Nature as object separate from Mind and Body, a criticism found in contemporary holistic thought.

Writers, like Tolstoy and Dickens, also found the rationality of science, manifested through emerging technologies which destroyed landscapes and people’s lives, as deeply anti-humanistic, anti-spiritual and disenchanting. In Dickens the Industrial Revolution in the form of the emerging railway network destroys the lives, relationships and homes of working people enriching cynical and unimaginative bankers. Tolstoy, as quoted by Weber, is even more lacerating:

‘Science is meaningless because it gives no answer to our question, the only question important to us, “what shall we do and how shall we live?”’ (cited in Bernstein, 1998, p. 38).

For many, then, like Tolstoy, science has nothing to say to the world of art and humanities, to human values and experiences. A foundational problem here is in the naturalistic fallacy of David Hume, in which moral guidance on the way we act in the world cannot be inferred from descriptive statements, also known as the is-ought dichotomy (Hudson, 1969). There are no moral or ethical inferences we can draw from the statements that the formula of water is H₂O or that the leaves of oak trees contain chlorophyll; the latter are facts and have no normative meaning. This distancing of science from emotions and justice was not only a flagship of those who saw the cold rationality of science as alienating. Some scientists and science educators approve of this dichotomy, upholding the unique epistemology of science in discovering facts about the world (Atkins, 1995; Wolpert, 1994). In terms of science teaching and learning, Hume’s naturalistic fallacy was invoked by a science educator fulminating against attempts to introduce controversial socio-scientific issues, in the form of ethical judgments, into school science lessons.

Science is a discipline concerned exclusively with the reliability that can be attributed to factual (‘is’) statements as a result of empirical investigation. It is widely recognised that ‘is’ statements in science cannot be turned into the ‘ought’ statements of moral discourse. For example, science can fairly accurately judge the consequences of bringing together a number of subcritical masses of U-235 above a densely populated geographical area. It can say absolutely nothing, however, about whether such an action would be right or wrong. (Hall, 1999, p. 15.)

The underpinning of such an insistence on separating the descriptive and normative worlds reflects a battle between traditional and progressive views of the curriculum which have played out in one form or another over many years.¹ It found, for example, intemperate debate in the ‘Science Wars’ of the 1990s in which those advocating a sociology of science, and science as a relativist cultural artefact, or as a myth (Collins & Pinch, 1998) from broadly social construc-

tivist perspectives were met with scorn by those defending its realist foundations and rational practise (Gross, Levitt, & Lewis, 1996).

Traditionalist views are deemed to hold with a model of curriculum in which certain subjects or disciplines have an authority, concepts and epistemic structures which are irreducible to other subjects. Hirst and Peters' (1970) conceptual analysis of the curriculum yields forms of knowledge, each with a 'distinctive type of test for its objective claims' (p. 63). In the case of physical sciences, this involves the use of concepts for what is sensed in the outside world, and abstract terms which distinguish science such as 'space', 'time', 'electron spin' from terms such as 'ought' and 'intention'. The latter involve no particular sense experience or empirical method but belong in the domain of moral knowledge.

This view is consistent with Haack (1996) who argues that while social judgements influence what science is done and how it is practised, these are contingent and extrinsic to science practise. Donnelly (2004) distinguishes between inquiry in science and STS in addressing curriculum reforms. At the level of school science, the natural sciences 'seem unlikely to display that *radical*, and arguably self-renewing, indeterminacy which is characteristic of the humanities. The natural sciences seek and value closure in a way which is alien to the humanities.' (p. 779).

Although moral knowledge is deemed irreducible to scientific knowledge and vice versa, scientific knowledge and evidence can be used to substantiate moral judgments. It seems absurd, for example, to make any judgment about the rights and wrongs of the uses of nuclear weapons without some understanding of what nuclear weapons are and in which circumstances they become lethal. Such scientific knowledge might be necessary for moral and ethical judgments but, it is argued, not sufficient on its own. Hence the conceptual integrity of science is conceived as quite separate from that of morality and the humanities more generally. How to justify interdisciplinary arrangements is therefore problematic where priority is given to the integrity of particular forms of knowledge. In such circumstances it is unsurprising that many science teachers prefer to 'keep to the science'.

Ontological reductionism also presents obstacles to curriculum integration by removing the distinctiveness of subjects which are not physical sciences. In the case of science an entity such as liquid water is comprised of smaller and simpler entities. Pure water consists of units of H₂O bound by electrostatic forces, known as hydrogen bonds. These units in turn consist of atoms of hydrogen and oxygen with spinning electrons and inner nuclei which are themselves comprised of yet smaller quantum entities. In terms of science-society formulations ontological reductionism would imply that since all natural systems are based on quantum, atomic and molecular reactions, the same also applies to social interactions which are a priori natural. Many physico-chemical events are explained in relation to foundational phenomena such as energy processes and forces between atomic particles. In biology, macro-characteristics such as disease can be explained through genetic expressions and interactions. Consciousness, likewise, becomes reduced to more basic neurological interactions.

Within the sciences there would be a hierarchy from physics through chemistry to molecular biology and biochemistry to physiology, behavioural biology, and so on, through to psychology and social psychology. So, physics can be explained within its disciplinary conceptual structure. Biology cannot explain physical and chemical phenomena but biology can be understood in terms of physico-chemical principles. So, fundamental subjects such as mathematics and physics are seen to provide the basic schema for subjects like biology, and the social sciences.

Pedagogy

As described above there have been reforms which have attempted to integrate social, historical and philosophical aspects with core descriptive knowledge. This process has not always been a smooth one and empirical studies demonstrate some of the difficulties teachers have in teaching socio-scientific issues (Day & Bryce, 2011). Some of these have been perceived by teachers as due to curriculum constraints and time (Levinson & Turner, 2001), some to a recognition that many socio-scientific issues are too complex to teach in the classroom (Dawson, 2000; Thomas, 2000).

A more substantive issue arises from the science content that is taught. Ryder (2001) identified a range of socio-scientific issues wherein the science content taught in the curriculum could not be used to support functional decision-making. Such aspects have been identified in a range of socio-scientific contexts where expert technoscientific knowledge has been ineffective in helping lay people to navigate scientifically based issues which affect them such as the pollution of waterways (Lee & Roth, 2003), tending for a Down Syndrome child, coping with effluent from a chemical factory (Layton, Jenkins, Macgill, & Davey, 1993), dealing with radiation from mobile phone masts (Drake, 2006).

Research evidence suggests that when students discuss socio-scientific issues they rarely draw on their own scientific knowledge (Albe, 2008) although Nielsen's research (2011) shows that in certain conditions of argumentation scientific knowledge is used for persuasive purposes.

What needs to be known for using scientific knowledge is therefore context dependent, and often what needs to be understood is not the content knowledge but the trustworthiness of the scientific sources, their reliability and students' commitment to the problem being addressed (Bouillon & Gomez, 2001). Although there is unlikely to be any straight-forward relationship between scientific knowledge and its social application that does not mean there is no relationship. And how far is an understanding of that relationship justified in a school science curriculum?

A response to empiricism and reductionism

Much of the debate about facts and values has been at risk of being fetishised both by those sceptical of the claims of science practise and those who are fervently in support. The problem surrounding claims made for omitting values discourse from science subject teaching and learning derive from the heavy dichotomisation made between facts and values by logical positivism where only facts were empirical and had any rational meaning. Values were preferences without foundation (Abbott, 2001), hence not subject to rational assessment or reflection, a view that too frequently is used to staunch discussion (Hand & Levinson, 2012).

While conceding factual statements are not the same as value statements, dichotomising takes their disjunction a bit too far. Epistemic values, for example, influence theory decisions based on criteria such as simplicity, coherence, plausibility (Putnam, 2002). Paul Dirac's conception of physics was infused by the aesthetic – 'a physical theory must possess mathematical beauty' (Kragh, 2002); values presuppose the construction of scientific theories and their evaluation.

Scientific facts such as evolutionary relations, the motion of the planets, the arrangement of the Periodic Table do not merely come into the world as sense data, they are interpreted by those qualified to do so, through collaboration, knowledge, experience and through historical judgment. Nor are these interpretations necessarily free of distortion through power relations and cultural prejudices evidenced, for example, by the account of the discovery of Neptune (Kosso, 2008).

The language we use to describe facts are 'entangled' with values (Putnam, 2002). Describing a room as cold (or in scientific terminology at a low temperature) is a commonsensical means of conveying information that the heating ought to be switched on, the doors closed, or dress in warmer clothes. The context in which it is said implies both some response, and a preference – it is better to take some action to avoid being cold. Some descriptive statements presuppose value conditions. To assert that copper is a better conductor of heat than polyethene is both a statement in factual form and a value statement.

So, the practise of science, the terminology used in scientific discourse in evaluating theories, is 'entangled' with the language of values. To what extent, then, can values and other school subjects play a role in the broader aims of school science education?

From the perspective of critical realism

I want to begin with an exploration of the problem of ontological reductionism, that more complex entities are constructed from simpler entities. Can the perception of the beauty of twilight on a clear autumn evening be explained solely on physico-chemical interactions? Intuitively it seems odd to do so.

A simple chemical example would begin to illustrate this problem. Pure water consists of hydrogen and oxygen atoms bonded together. However, the chemical properties of water are completely different from those of hydrogen and oxygen alone. At room temperature hydrogen and oxygen are gases; water is a liquid. Hydrogen and oxygen support combustion, water is used to quench flames. Although the chemical constitution of pure water is solely hydrogen and oxygen there is clearly a great deal of difference between the components separate and when combined; in other words water has *emergent* properties in relation to hydrogen and oxygen. But there are some further factors.

As everyone knows the formula of water is H₂O. It signifies that in one molecule of water there are twice as many hydrogen as oxygen atoms where the hydrogen and oxygen atoms are chemically bonded to each other. In fact water molecules are not chemically discrete in the liquid and solid phases because they are joined by strong intermolecular bonds, called hydrogen bonds, arising from the polarity of the water molecule. Water can only accurately be described

as H₂O in very particular circumstances, when it has been purified in airless conditions, i.e. a vacuum. In everyday conditions liquid water dissolves oxygen and carbon dioxide so that the ratio of hydrogen atoms to oxygen atoms in a sample of water is considerably less than 2 to 1.

Laws and principles such as the Laws of Motion, Laws of Falling Bodies, the Gas Laws appear in almost all high school science curricula. They are expressions of regularities and relationships (Chalmers, 1999). So, the Gas Laws relay the fact that when pressure is applied to a gas under certain conditions, temperature being kept constant, the volume decreases inversely in relation to the pressure. But there are two aspects of scientific laws which are relevant to this argument: first, they tell us nothing about the underlying mechanisms, and second, they only apply under very specific closed conditions. No gas exactly obeys the gas laws.

Taking the Law of Falling Bodies as an example it becomes clear that this cannot be easily demonstrated in everyday conditions. Drop a golf ball and an oak leaf from a height at the same time and the golf ball will always reach the ground first. Only when this experiment is performed in a vacuum will the law hold. But it is rare to find a vacuum in the real conditions of Planet Earth. (Of course, such conditions do hold beyond the confines of the Earth's atmosphere. Outer Space can be considered a closed system.)

Experiments such as those which demonstrate the Law of Falling Bodies are carried out in necessarily highly controlled, closed conditions. This is because there are so many factors which control, for example, the acceleration of objects as they fall that it is necessary to remove all other conditions except the one being tested for. So here, the causal factor that is being tested, the Earth's field of force can be identified free of other restraining factors. It allows scientists to identify those mechanisms operating in a causal relationship.

One way to explain natural phenomena in open conditions is to assert that the things that make up our world have the powers to make things happen, i.e. they have causal powers (Chalmers, 1999). (The word 'power' is not used here in the strict scientific sense but in the sense of the capability of making things happen). Water quenches thirst as well as flames, bells clang, cats leap, copper wires have the power to conduct electricity, polythene has the power to prevent the flow of an electric current, moving air resists the fall of objects of low density and high surface area, at very high temperatures oxygen atoms have the power to combine with hydrogen atoms so that a completely new substance *emerges*, water. Planet Earth has the power to exert a force on objects but this power can be hindered by flowing air. These powers – when exercised – produce certain events. The cat might be snoozing in the sun but under certain conditions, possibly when the bell clangs, it can leap.

So, when events take place in open systems, such as autumn leaves falling slowly and buffeted about by air currents, they are underpinned by a multiplicity of interacting mechanisms which can be isolated and understood in the specially closed and controlled conditions of scientific experiments. In a critical realist approach events are denoted as *actual*, they are those that are *experienced*. Events, however, can be *explained* by mechanisms or underlying structures. Take, for example, a common chemical reaction – the rising of dough when baking a cake. The event – the rising of the dough – is experienced by observation, for example, both by smell and by sight. The perception or experience of the dough rising is in the domain of the Empirical. The Actual consists of both the event – the dough rising – and the experience. Events do not depend on being experienced but the domain of the empirical depends on events taking place. The raising of the dough has to be explained. Here a range of mechanisms, not easily observable, are taking place. The dough is put in the oven perhaps in preparation for a party. However, the raising of the dough can be explained by a series of chemical reactions taking place facilitated by the enzymes in yeast. These mechanisms are in the domain of the *Real*: electron exchanges between atoms facilitated at a certain temperature and by enzymes, as well as the social conditions which resulted in the cake being placed in the oven in the first place.

Can mechanisms such as electron transfer be described as *real*? From a positivist perspective they can be looked upon as theoretical explanations which can be shelved when more compelling evidence comes along to either refine the explanations or where they can be disposed of completely, for example, the eighteenth century phlogiston theory of combustion being replaced by the oxygen theory of combustion. But while mechanisms cannot necessarily be perceived they can be invoked on causal criteria (Collier, 1994). Viruses and bacteria cannot be observed under ordinary circumstances but in cases of food poisoning, meningitis and influenza no one discounts their role. Of course, during the course of history other causal agents have been ascribed but it is this fallibility in depicting a mechanism which is a *critical* view of reality. And, in fact, hypothesised entities such as bacteria, viruses, molecules and atoms have eventually come to be observed through the aid of instrumentation.

The reality of these mechanisms is what distinguishes Critical Realism from Empiricism, Idealism and Naïve Realism. What is postulated in critical realism is ontological realism with epistemological relativism, i.e. the need to distinguish between what exists (the intransitive dimension) and what is known (the transitive dimension). Scientific theories and laws (those operationalised by mechanisms in open systems) explain the world as best as possible but are always open to correction and change. Science is a social activity where its theories are subject to change and correction through errors of the past and no doubt errors of the future, i.e. science is fallible. But that does not mean theories cannot be independently validated and compared for explanatory competence. By locating explanatory entities as sense data, empiricism denies the reality of underlying structures which can exert causal powers when exercised (Bhaskar, 2011; Collier, 1994). Idealism denies the objective reality of the world, and therefore that such mechanisms have explanatory power beyond discursive acts. Naïve realism, as opposed to the depth realism of Critical Realism, identifies an eventual correct description of the world thereby conflating what is known with what exists.

Stratification and emergence

Earlier I raised the problem of ontological reductionism, that complex entities can be explained by simpler ones. The case of water in relation to its component atoms demonstrates emergent properties, and this emergence also applies to social phenomena. A school consists of people, buildings, materials but is more than and distinct from the sum of these entities. As this relationship develops and emerges between the various entities both the school as an institution and its constituents change too. A tree is composed of many diverse organic and inorganic materials but its activity and life-history, as well as its influence on surrounding biota are much more than the sum of its parts. Lowenhaupt Tsing's (2015) account of the complex and symbiotic 'entanglements' of lodgepole pines in denuded forests with mushroom fruiting bodies, and the effect on forest picking and the global capital flows generated for specialist mushrooms, demonstrates the importance of assemblages and the complex action of many different mechanisms influenced by and acting in relation to each other.

In terms of the laws or mechanisms that govern Nature and Society it is possible to talk about different strata of being. Non-living materials in the most basic stratum are governed by physico-chemical mechanisms, living things by physico-chemical and biological mechanisms; social institutions by social laws as well as physico-chemical and biological mechanisms. While entities are governed by these laws/mechanisms they are not determined by them. As I play tennis I am limited by the capacity of my body cells to process oxygen and glucose and supply my muscles and many other physiological processes but these cannot determine how I play.

Just as there are strata of entities, there are strata of mechanisms increasing in complexity from relatively simply physical and chemical mechanisms, through biological to psychological, social, economic mechanisms and so on. But actual events cannot be stratified in this way. The deoxygenation of a pond and the consequent disappearance of fish and frogs are due to chemical changes in effluent as a result of changes in local regulations on discharge of waste which has a deleterious effect on biological functioning of fish and frogs and plants. Such an outcome might affect social, leisure and economic activities when people no longer come to fish in the area. Mechanisms act in complex ways in relation to each other to bring about certain events or happenings.

What, then, are the implications both for doing science, and for what should be taught in science curricula, in schools? In doing science – i.e. testing ideas through experimentation, evaluating data, discussion with colleagues – rational (and non-rational) processes are involved which are emergent and distinct from lower order strata such as physiological processes. Living beings such as mammals are more than physico-chemical and biological mechanisms which is why there is outrage when they are kept in cramped conditions restricting their natural freedoms. Human freedom to do science means deploying those causal powers associated with rational thinking.

But there is also a more crucial implication. It also means recognising that doing science is governed by but not reducible to lower order mechanisms. There are also other mechanisms operating in concert with each other: social mechanisms that regulate what can be recognised as scientifically reputable. So this freedom to practise science is not unrestrained but entangled with other emergent mechanisms. Human freedom is 'something that belongs in a realm apart from science, but something whose basis would have to be scientifically understood'. (Bhaskar, 2008, p. 112). Our freedoms and commitments to experimentation and gathering greater knowledge and understanding about Nature must be based on certain conditions being present, for example, a healthy diet and working environment, as well as a

critical and responsive scientific community. It also follows from this that to understand events such as hunger, love, the effect of genetic conditions, scientific knowledge is but one component among other disciplines.

If science is therefore about human capabilities to ask questions about the way Nature operates and replacing inadequate theories with better ones then certain kinds of questions follow which are interwoven with the nature of human freedom. For example:

- If we have an understanding that realising the possibilities of experimenting and gaining more knowledge of the world depend on a balanced and healthy diet why are such conditions not available to all human beings?
- If scientific knowledge enables us to understand the potential devastation to all living beings of a critical mass of U-235 what can be done to prevent such devastation?
- If we understand the processes of global warming together with the attendant uncertainties of knowledge and the consequent risks why is it so hard to get agreement on action?

Some examples

To summarise: there are two ways in which I see social justice presupposing an epistemology of science teaching and learning in school. The first is that the act of investigating the world entrains a notion of human freedom. The second is that any event cannot be adequately understood by one stratum of explanation. If students are to make sense of events they cannot be confined to understanding mechanisms in one stratum, in other words, the Vision I view of the science curriculum and its implied monodisciplinarity.

To take an example. The globalised world depends on the use of digital technologies, the ability for information to flow around the world at unprecedented speeds. Almost all school students in industrialised countries use these technologies in communication and learning. Of course the use of this hardware has a social effect, and in science lessons it has been suggested that research on the radiation of cell phones might have an effect on the brains of young people (Albe, 2008; Christensen, 2009). While much of the work on socio-scientific issues explores the effects of consumption and the concomitant risks (Christensen, 2009) through the applications of science, little attention is paid to the conditions of production. Microchips are essential for the mass manufacture of computers, cell-phones, and is the hardware on which all social media and digital communications depend. Two metals which are core materials in semi-conductor components are tantalum and niobium found in the mineral coltan extracted under duress and exploitative conditions in the Democratic Republic of Congo (Lalji, 2007). Without cheap sources of coltan – available through the restriction of human freedom of ‘unseen’ workers - affordable prices for computer hardware would be impossible. What makes the collection and flow of huge amounts of data, crucial for the development of scientific knowledge, is gained at the expense of those who are excluded from the possibility of using, and gaining from such knowledge. The event encapsulated in the production of digital technologies is underpinned by mechanisms, real to those who suffer oppression at their actualisation, which incorporate physico-chemical, social and economic mechanisms entangled with each other.

Events such as the production of microchips, the destruction of a pond alert us to different mechanisms overlapping, resulting in particular events or happenings which can be explained. Criticality assumes the need to both understand the structures that lead to particular outcomes but to use our knowledge to transform them. A system that suffocates organisms whether rational humans, non-human mammals and living things more generally to flourish as evolved beings – through lack of access to nutrients to promote life, sustainable habitats, systems of production which support the faculties of some at the expense of others – is self-evidently non-conducive to the capabilities necessary to practise science.

The predominant approach in schools is to examine the application of science broadly through the use of social contexts to illuminate scientific ideas, a Vision II approach (Roberts, 2011). But applying science as studied through closed systems to the real world, or privileging science as the main explanatory source, fails to acknowledge the complexity of the way the world is structured and to produce solutions which ignore social, economic and political structures. A counter to this position would be to say, understandably, that that is simply expecting too much for teachers. It is difficult enough to teach the basics of The Periodic Table without having to incorporate sociology, history, politics, mathematics.

But, as the research shows on student disaffection, one of the problems is that school science does not reflect life and seems inert because the real world is open, complex and uncertain. Another approach is to acknowledge complexity and

uncertainty. A teacher who asked his students to draw a graph of temperature against time as water heated was able to help his students understand that none of the points of the data perfectly fitted the graph. So, rather than illustrating a pattern the students both recognised the pattern but were intrigued by the opportunities open to them in exploring new ideas precisely because there is always a gap between data and representations, and between what is known and evidence (Author, in press). Knowing the real effects on the environment of hydro-electric power stations can more easily help young people to explain both the process, its effects and what action might be taken.

Understanding this complexity can also start with very young children. One teacher having led a lesson in classifying solids, liquids and gases, asked the class at the end of the lesson whether their jackets were solid liquid or gas. The pupils looked mystified before one responded and said 'Miss. Clothes aren't chemicals.' The separation between school science and the world was manifest.

Very few materials are purely just one state of matter. Toothpaste has to have both the solid property of setting, the liquid property of flowing and the gaseous property of diffusing odour through the air. The same is true of jam which is often a composite of different materials. Milk has liquid properties but can be treated to produce substances like cheese with predominantly solid properties or butter which has both solid and liquid properties. Even metal blocks have a vapour pressure, particles drift off and become gaseous and these change under different conditions. Giving young people the tools to problematise given properties encourages the kind of reflection which deepens explanations, for example, moving from categorisations of states of matter to asking critical questions about how diverse properties are exhibited in different materials (Levinson, 2000).

In primary education water is a good subject to demonstrate how real mechanisms operate in different contexts. Aquatic organisms survive freezing conditions because water is unique in expanding when it freezes. Water provides the essentials for life – our bodies are mostly water – but it also transports harmful and toxic substances. The water cycle is a central component of weather systems. Water, then, is the vehicle for illustrating how different mechanisms generate circumstances on which all lives depend.

I will briefly discuss three initiatives. None explicitly draw on a critical realist approach but they serve to illustrate from different cultural and educational traditions how critically explaining the world through interdisciplinary approaches deepens understanding of social justice in a science context.

Socially Acute Questions (SAQs) (in French, Questions Socialement Vives) address urgent contemporary socially controversial issues (Simonneaux & Legardez, 2010) which adopt multi-disciplinary and didactically reflexive strategies. They are questions which address controversial issues, challenge social practices and their representations, where there are significant differences among experts. Questions which arise in a post-normal context (Ravetz, 1999), in other words, high stake technologies beset by risk and uncertainty such as the social applications of nanotechnology, demand explanations from different disciplines (layers of explanations/mechanisms): science, politics, mathematics, sociology, ethics, economics, environmental science. They take into account didactical transposition, how knowledge is constructed and recontextualised from research programmes to that taught in schools and learned by students. Laying emphasis on the dialectic between theory and practise, SAQs incorporate the actors involved in a controversy, their interest positions, as well as looking through the lenses of different theoretical perspectives. For example, on an issue like teenage smoking, three aspects can be considered: concepts, ideologies and social practises, see [Table 2](#).

Table 2. An example of concepts, ideologies and social practices in a Socially Acute Question (teenage smoking). Table Layout

Concepts	Ideologies	Social practises
Physiology (effects on smoking on diffusion of oxygen and carbon dioxide) Social psychology (what draws young people to smoking) Economics (how are cigarettes marketed) History and geography (when did smoking emerge as an activity and how is tobacco geographically distributed) Statistics (what do statistics tell us about the relationship between smoking and disease)	Neoliberal (the market should control the distribution of products. If young people want to smoke that is up to them) State (The State has a responsibility for the health of its citizens. It has to balance rights with responsibilities, hence limit the production of materials that are known to damage health)	Marketing Politics Youth culture Media

Starting from a critique of neoliberalism and capitalist science education, STEPWISE, (Science & Technology Education Promoting Wellbeing for Individuals, Societies and Environments) (Bencze, 2017; Bencze & Carter, 2011) aims to promote activism where young people use their science knowledge to ameliorate their lives and society more generally. It is based on five guiding principles.

Holism addresses what is seen as individualisation and decontextualisation in the curriculum. The model of STEPWISE incorporates four domains which are studied *in concert* to achieve action and change. The four domains are Products Education (learning about the principles and functioning of scientific laws and theories), Skills Education (asking good questions, evaluating and displaying data, communicating findings), STS(E) education (learning about issues such as climate change, ‘free’ trade, fuel sources), and Students Projects (inquiries into collecting evidence which might include correlational studies such as surveys, as well as experiments). These together are aimed towards Actions such as lobbying power-brokers, changing one’s own practises and educating others about these issues.

Altruism: Orienting learning towards the common good rather than possessive individualism.

Realism: Evidencing the complex interactions between different fields such as science and technology.

Egalitarianism: Disturbing ‘school science networks in ways that may engender social equity’ (Bencze & Carter, 2011, p. 660).

Dualism: Engaging students in interactions between phenomena and events such as the effects of sugary drinks on learning or the use of sun-tanning parlours, and their representations such as inscriptions of their own correlative studies on these topics and critiques of press reports.

Vision III (Sjöström, 2017) is the third initiative and based on a critique of Visions I and II. It incorporates moral-philosophical-existential perspectives with socio-political actions. For example, chemistry education is often represented as understanding the links between the triplet of macro (experiences of chemical phenomena such as the reactions of metals in acid, oscillating reactions, redox reactions), micro (explanations for reactions at atomic/molecular levels) and the symbolic (models, chemical equations) (Johnstone, 1982) which reflects a Vision I approach. Vision II explores the socio-economic ramifications of chemistry applications. Vision III extends this to a post-humanist critically reflexive perspective in which the socio-political dimensions of chemistry and science more generally are set within a risk society (Beck, 1992), and attention drawn to how we should act within attendant uncertainties in a planet under environmental threat.

SAQs, STEPWISE and Vision III are examples of initiatives which reflect a broader critical realist approach, gears science understanding to life as experienced. Other examples come from school students taking environmental action through distributed learning (Lee & Roth, 2003), urban science with marginalised children (Calabrese Barton & O’Neill, 2008) and citizen activism (Pouliot, 2015).

Concluding comments

The purpose of my critique of school science education is to find a means of gearing it to social justice and social transformation. An objection is that such an approach looks too much like indoctrination. There are two main responses to this criticism. First, I use the term social justice as reflected by Roy Bhaskar’s term of human emancipation (Zembylas,

2006) which subsumes the necessary conditions in which science can be done as well as a commitment and aspiration to act. The initiatives I have selected do emerge from critiques of the political orientation of education in a capitalist society. To raise awareness of possible sources of oppression is a perfectly legitimate educational activity in the spirit of such educators as Ranciere and Freire (Galloway, 2012). But such a critical approach also entails awareness and critique of putative solutions which sometimes remain absent in some educational agendas. Secondly, the initiatives discussed mainly focus on social action. What about aspects of awe, wonder and curiosity which are so important a part of the scientific enterprise, for example, the understanding that nature appears both organised and uncertain? This presupposes an understanding of how this organisation and patterning, the regularities uncovered through Laws, are discovered but also their historical context and their realisation in open systems.

Implementing such an approach in schools is a bigger question. But it can be done in small stages, for example blurring boundaries as in the example above of states of matter which open up new areas of inquiry, questioning data from everyday activities such as heating water, or observing the changes in a small ecosystem.

Disclosure statement

No potential conflict of interest was reported by the authors. [AQ2](#)

Table 1. Three domains within a critical realist approach. Table Layout

	Real domain	Actual domain	Empirical domain
Experience (e.g. observing changes in dough)	/	/	/
Event (dough rising)	/	/	
Mechanism (chemical and social changes which result in baking of cake)	/		

Notes

¹There is no clear distinction between traditionalists and progressives. There are many grey areas. This is simply a ploy to set up the main terms of the debate.

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