Transforming science education for the Anthropocene – is it possible?

Jane Gilbert

Auckland University of Technology

Auckland, New Zealand

Email: Jane.Gilbert@aut.ac.nz

Tel +64 9 921 9999 ext 8159

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Abstract

Since its inception science education has been the focus of a great many reform attempts. In general the aim has been to improve science understanding and/or make science study more interesting and/or relevant to a wider range of students. However, these reform attempts have had limited success. This paper argues that this is in part because science education as a discipline has some “blind spots”, some unacknowledged assumptions that obstruct its development and make it immune to change. While this has long been a problem, the paper argues that, in the new, “postnormal” conditions of the 21st century, it is now imperative that we see these blind spots, and think differently about what science education is *for*.

School science as we now know it (along with the other school subjects) developed as part of, and in parallel with, modern economies/societies, which in turn depended on the burning of fossil fuels. However, because this period of “carbonised modernity” is now coming to an end, many of the assumptions it was built on must be re-examined. This has (or should have) major implications for science education.

Via an exploration of three very different “orientations to the future”, the paper aims to provoke discussion of how science education could be reconceptualised to support our transition into the post-carbon, Anthropocene era.

Key words

Future of science education

Postnormal science education

Anthropocene science education

Immunity to change

Transforming science education for the Anthropocene[1] – is it possible?

> The challenge is not that we must find ways to 'know' the future, rather we need to find ways to live and act with *not-knowing* the future (Miller, 2011a: p.1).

> The point of education is never that children or students learn, but that they learn *something*, that they learn this for particular *purposes*, and that they learn this from *someone*. The problem with the language of learning and with the wider 'learnification' of educational discourse is that it makes it far more difficult, if not impossible, to ask the crucial questions about *content*, *purpose* and *relationships* (Biesta 2012, p.36).

This paper joins the already sizeable body of work arguing for change in science education. It is intended to contribute to the debate on why change in science education is so difficult by raising the possibility that there are "blind spots" in our vision. Being "in crisis" seems to have been a feature of science education since its inception (DeBoer 1991), however, I want to argue that the transition into the Anthropocene could be the "crisis to end all crises", the catalyst needed to provoke real change.

The paper's starting point is that if we accept that carbonised modernity is coming to an end, then we have to accept that science education as we have known it must be transformed. Substantial rethinking−of its *content*, its *purposes*, and its *relationships*−is required. This kind of thinking is incredibly challenging, because the conceptual categories that structure our thinking are themselves part of the problem. We can't think outside these categories: we can only, to use Derrida's term, put them "under erasure", signal that they are problematic, and may eventually need to be "erased", while also continuing to work with them. However, despite the difficulties, I think we have to attempt this work.

The paper begins with an overview of various change initiatives in science education. It then outlines recent work calling for schools to be "revolutionised" for the "new times" of the 21st century. It looks

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1 The Anthropocene is the name being given to the advent of a new geological epoch, beginning roughly with the Industrial Revolution and the widespread use of fossil fuels, in which human activities came to have a major influence on the earth's physical processes. The term is derived from the Greek: 'anthro" meaning 'human', and "cene' meaning 'new' (geological era) and was coined to signal the termination of the Holocene. Burning carbon sequestered over hundreds of millions of years from the atmosphere, via living processes, has vastly increased atmospheric carbon dioxide levels, which has in turn triggered a rise in mean global temperatures. This is expected to have a major impact on world sea levels, weather systems, and ecosystem stability, which will affect the habitability of the planet for humans, and have major implications for human social, political and economic life. As is widely discussed, collectively we have not yet managed to put in place measures that could reverse or delay these trends, nor have we developed strategies for adapting to or mitigating their likely effects.

at the implications of this call, in its wider intellectual context, and then for science education. The paper then sets out three possible scenarios for science education's future, and suggests some strategies for seeing the "blind spots" that seem to make science education immune to change.

SCIENCE EDUCATION – THE PARADIGM?

Thomas Kuhn's much-cited work of nearly half a century ago (Kuhn 1970) describes scientific progress as occurring, not via the gradual accumulation of knowledge, but as a series of revolutions—or "paradigm shifts"—in thought. There are long periods of what he calls "normal science", "puzzle-solving" activity structured by the current way of conceptualising the field and its problems. Anomalies emerge, but the puzzle-solvers work to explain these from within the current paradigm. Eventually, however, these anomalies build up, to a crisis point. There are disputes, which can be bitter, and calls for change. If these are not resolved, the field undergoes a paradigm shift, a radical departure from the old way of seeing things, which is replaced by an incommensurable new view. The field moves off with new energy, in a new direction and/or with new conceptual tools, but it eventually settles down into a new period of "normal science", within the new paradigm.

The defining feature of science education, as it has developed over the last century or so, has been "puzzle-solving" activity around two basic questions: how to get students to learn science *better*, and/or how to engage *more* students in the study of science. Anomalies have arisen, and there have been many calls for change, over several decades. A major theme has been the disparity between what school science education programmes offer, and the needs and interests of young people. In research project after research project this disparity has been explored, and many solutions have been proposed. Despite all this, participation rates in science study (once it is no longer compulsory) continue to decline, as do levels of interest/engagement in science, and student understanding of science does not seem to have improved (see, for example, OECD 2007, 2009; Osborne *et al* 2009; Tytler 2007).

Partly, but not entirely, because capability in science (and a science-supportive public) is thought to be key to economic progress, every few years a "crisis" in science education is identified (Aubusson 2013, Toscano 2013). Reports and new research are commissioned, new approaches to teaching are recommended and new curricula come into effect (see, for example, Gluckman 2011; Bull *et al* 2010; Tytler 2007; Bell 2005; Goodrum *et al* 2001; Miller & Osborne 2000). Some of this thinking finds its way into policy rhetoric and classrooms, but there is no paradigm shift in thinking or practice, and things continue much as they always have.

As DeBoer (1991) shows, this is a well-established pattern. Over the century or so of its existence, science education debate has alternated, with a periodicity of about twenty years, between two competing ontological positions. In one position the disciplinary requirements of *science* are emphasised. Education here is a technical matter - how best to instruct or initiate students into the discipline. The second of the two positions emphasises *educational* considerations. The focus is on learners, and how best to foster their intellectual and socio-cultural development. Science is seen as one (of many) contexts within which this can take place.

In the last couple of decades this pattern has continued. Research in science education has had a strong focus on developing and evaluating initiatives designed to make science more relevant and interesting for learners. One approach has been to advocate changes to the curriculum content. Science educators have proposed a broadening of the traditional knowledge base of school science to include, for example, science, technology and society (STS) studies, the history and philosophy of science (HPS), environmental science, "issues-based" science, the study of socio-scientific issues (SSIs), ethics, "nature of science" studies (NoS), science "capabilities", and, more recently, making futures studies part of science education. Science "literacy" and/or "citizenship science" as key purposes of science education have been much-discussed. Another approach has been to advocate the development of better teaching and learning methods. Constructivist pedagogies, and a focus on social, cultural and/or affective dimensions of an individual's learning, have become, at least in theory, the "new orthodoxy" (Fensham 1992). Alongside this, the "science for all" movement has argued for changes to science education's content and teaching methods to make more attractive to individuals from under-represented groups, in particular, students from indigenous and/or lower socio-economic backgrounds, and girls.

While there have been dissenters, and there are signs that the *science* side of DeBoer's pendulum might be in the ascendancy again,[2] it seems fair to say that the *education* focus has, in theory, predominated for a generation or so. However, below the surface rhetoric, we find a different story. A clue to this is science education's tendency towards what David Perkins calls "aboutism" (Perkins 2009, p.5): that is, the predilection to re-orient all new initiatives, whatever their putative intent, as new knowledge to be learned, usually *in addition to* the previously accepted knowledge base. For example, the "nature of science" (NoS) initiative: this was originally intended as a way of moving science education away from its traditional focus on "the facts" of science, to approaches that were supposed to facilitate *critical thinking* about science and the epistemological frameworks on which it rests. However, in practice, NoS has become just another set of concepts students must learn *about*. In some jurisdictions these are even expressed as sets of propositions that need to be understood by students and by teachers (Lederman 2007, Hipkins 2012). Similarly, the introduction of "socio-scientific issues" was supposed to be a way of helping students *critically* engage in debates about science's relationship with its socio-cultural context (Zeidler *et al* 2005, Zeidler & Nichols 2009). However, possibly through a commitment to science's objectivity, many teachers aim to treat SSIs in a "balanced" way, *avoiding* discussions of economic or political interests and/or socio-cultural values (Hodson 2003). The result of this is a tendency to teach *about* the social, cultural or ethical issues associated with various scientific or technological practices: that is, giving students more "stuff to know", not providing them with appropriate contexts to develop the critical thinking skills they need to participate productively in debates about these issues. One more example, relevant to this Special Issue, is recent work advocating the incorporation of Futures Studies into science education programmes. This work sets out approaches to science education which involve students learning *about* the discipline of Futures Studies, ostensibly as a way of preparing them *for* the future (e.g. Jones *et al* 2012, Lloyd & Wallace 2004). While apparently contributing to the education side of DeBoer's pendulum, these approaches are also likely to produce yet more "aboutism", the "collecting" of new concepts, as opposed to fostering students' capacity to think *critically*, to think for themselves, in increasingly complex ways, about the future.

2 At least in recent policy rhetoric – see, for example, Gluckman (2011).

My point, in drawing attention to this, is to find a "way in" to the deconstructive process that I think will be necessary to move science education out of the impasse DeBoer describes, into a new space from which it might be possible to address the challenges posed by the Anthropocene.

Why is it that, while science educators *say* they are committed to meeting the needs of learners in their socio-cultural context/s, they default to "aboutism"? Is there something in the way science educators are socialised that predisposes them to think like this? Or does science education attract people who think like this? Or does this have something to do with how science education is structured, with how it has developed as a discrete field of enquiry? I don't think we know the answers to these questions, and I think this is part of the problem. In this paper I want to argue that we need to look at ourselves, to dig up some of our assumptions about science education – what it *is*, and what it is *for*, and our assumptions about science, education, society, and the future. I think we are likely to find some "blind spots" that are obstructing the changes we advocate, but never really action. Looking to the future, if these blind spots are not addressed, science education will maintain its apparent immunity to change, and become increasingly anachronous. I return to the discussion of blind spots in the last part of the paper, but the next section looks at the various arguments for change in education generally. What is new and different about education's future and what are the implications of this for science education?

EDUCATION AND "THE FUTURE"

The last decade and a half has seen a proliferation of research and commentary on education's future. References to "future-focused" education, "21st century learners" "digital natives" and so on are now routine, particularly in policy contexts. This literature argues that that today's schools are not adequately preparing young people for the increasingly complex, uncertain, and fast-changing world of the future, and that the need for change is now urgent.[3]

A two part story underpins this literature. Part 1 lists some of the "mega-trends" driving the "paradigm shift" taking place in the world beyond education. This list usually includes the following. First is the "digital revolution" - the exponential growth in computing power and digital networks, and the implications of this for society, the economy and the nature and distribution of employment opportunities (see Kurzweil 2005; Brynjolfsson & McAfee 2011). Second is globalisation - the dissolving of boundaries between nation-states and their economies. Third is the development of new, "networked" forms of knowledge that are now "too big to know" (Castells, 2000; Weinberger 2011). Fourth is the projected shift in world order that is likely to result from the demographic and economic changes now well under way in, for example, the BRICS group of countries[4] (Marginson *et al* 2011). The fifth mega-trend encompasses the developments linked to the Anthropocene – climate change and the many other "wicked problems" we face in the 21st century.[5] These trends, it is argued, are likely to produce the end of work as we currently know it. Most manufacturing work, as

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3 See the following examples: Barber *et al* (2013), Beare (2001), Christensen *et al* (2008), Gilbert (2005), Khan (2012), Leadbeater (2011), Miller *et al* (2008), Miller & Bentley (2003), Murgatroyd (2011), Prensky (2001), Robinson (2011), Tuomi & Miller (2011), Wagner (2008, 2012).

4 BRICS refers to Brazil, Russia, India, China and South Africa.

5 The term 'wicked problem' is now widely used to refer to very complex problems that are difficult or impossible to solve – or even define - using the tools and techniques of one organisation or discipline. Because they have multiple causes and complex interdependencies, efforts to solve one aspect of a wicked problem often reveal or create other problems. See Conklin (2006).

well as whole classes of professional work, will be replaced by intelligent technologies (this will affect large sections of the current scientific workforce). The breakdown of nation-state boundaries will limit the ability to levy taxes, which will in turn limit the capacity to provide public services, invest in infrastructure, and so on. Social inequalities will increase. And then there's the physical effects of climate change. Taken together, these trends represent a strong challenge to the current order, and to "known" ways of doing things. However, the response, in most "first world" countries, has been to strive to maintain competitive advantage, to mitigate the risk of economic and/or political oblivion. This is where education comes into the picture. In Part 2 of the prevailing story, schools are portrayed as having failed to respond to these trends, as being inert, outdated, obsolete, and no longer "fit for purpose". Part of another age, they rely on, and are embedded in, "old knowledge", "old systems", and "old technologies". We need, the argument goes, to "revolutionise" education, rebuild it from the ground up, so it can better meet the needs of these "new times".

While this story is pervasive and well-known, it has *not* produced a revolution in educational thinking. Schools continue to be organised by the same knowledge, the same systems, and, to a large extent, the same technologies (in the widest sense of this term). In the policy rhetoric on education's future, two "big ideas" predominate. The first is better system *performance* – a "future-focused" system is one that produces higher rates of student achievement, and more students with tertiary qualifications. The second is *digitisation* – "e-learning" and better data management. These ideas are, however, a finessing of "old" understandings of education, not a framework for preparing young people to live, think, and act in tomorrow's world.

Education's apparent inability to engage with "futures" thinking, like science education's inability to find its way out of the impasse it is in, has to do with its genealogy, its connection to some "big ideas" that, in the postmodern Anthropocene age, may no longer apply. Modern education was forged in the transition from agriculture-based economies and societies to predominantly urbanised, industrially-oriented ways of life. The development of mass schooling was important for its role in producing the human resources—and consumers—needed in modern economies. The "subjects" of the modern school curriculum, including science, were developed to support the growth of modern economies/societies. However, modernity was based on burning fossil fuels, and it seems that this period in history, characterised by some authors as "carboniferous capitalism" (e.g. Newell & Patterson 2010), is coming to an end. This has implications beyond the economic context.

Sociological and philosophical analysis of the Anthropocene's implications for modernity's key assumptions is well under way. A case is being made by some scholars for a new paradigm of "post-carbon" social theory, for a reworking of the modern conceptions of society, politics, and the economy (e.g. Newell & Patterson 2010, Irwin 2010, Urry 2011, Elliott & Turner 2012, Klein 2014). Commentators in other disciplines talk about the shift to "postnormal times" (e.g. Sardar 2010, Ravetz 2011, Slaughter 2012). This term was first used in the 1990s to describe changes in science (e.g. Ravetz 1993), but it is now widely applied across a range of very different disciplines. Key to its meaning is the recognition that things are no longer certain, simple or stable (if they ever were). Uncertainty, complexity, chaos, and contradictions are the "new" normal. As Ziauddin Sardar puts it:

> We live in an in-between period where old orthodoxies are dying, new ones have yet to be born, and very few things seems to make sense. Ours is a transitional age, a time without the confidence that we can return to any past we have known and with no confidence in any path to a desirable attainable sustainable future. (Sardar 2010, p.435).

Everything is now complex – that is, deeply entangled, inter-connected, unpredictable, and open. Any given problem has multiple dimensions: there can be no "right" or "wrong" answers, just different ways to understand the problem. "Reality" is incomprehensible via the traditional disciplines, which rely on reducing the system to a selection of discrete units, inevitably leaving out key aspects. As Sardar puts it, in postnormal times, "business as usual" modes of thinking and behaving are "now dangerously obsolete": they are "an invitation to impending catastrophe" (2010, p.441).

If, as these theorists argue, we have moved into the postnormal, postcarbon, Anthropocene era, and modernity's key concepts no longer apply, then it seems we need to think again about the meaning of "education" and "society", and, following from this, the meaning (and purpose) of traditional school subjects, including science. Schools, if we continue to have them, will need to prepare young people for a *range* of different possible futures, including possibilities *other* than the "continued growth" model assumed by modern education.[6]

Some educational theorists are increasingly beginning to work with these ideas (e.g. Facer 2012, Milojevic 2005, Morgan 2013). A few, most notably Richard Slaughter, Noel Gough, and William Doll, have been working in this area for twenty years or more. However, apart from their work, I think it is fair to say that science education has lagged behind the other curriculum areas in debating these questions (this issue is of course now being addressed in this Special Issue). There are important reasons for this. One is science's deep connection to carboniferous capitalism. Another is that science and technology are routinely depicted *as* the future: that is, the idea that the future will be "built" via advances in nanotechnology, biotechnology, IT and so on, and that science will "save" us from the problems we face. But science takes place in a social context. Science and technology do not, by themselves, shape the future: it is shaped by prior human choices about the values used to create and guide developments in science and technology (Slaughter, 2012). Science *education*'s future will similarly be shaped by human choices and values. In this paper I want to argue that we are at an important turning point. There are choices available to us now, important choices that will shape the future of science education and, if education really can have a role in this, the future of the planet.

As a way of trying to see outside the current paradigm, to imagine the kinds of spaces we need to make choices now, in this paper I have attempted to set out three broad scenarios for science education's future, written as if we are looking backwards from a point in time a decade or so in the future. These scenarios or, more properly, "orientations to the future", are of course simplifications. They are not predictions: their purpose is to serve as a starting point for the discussions we need to have about the range of values and assumptions that *could*—and hopefully will—shape science education's future development.

ORIENTATION 1: "BUSINESS AS USUAL"

[6] The futurist Jim Dator (2009) sets out four clusters of what he calls "images of the future": "Continued Growth", "Collapse", "Disciplined Society", and "Transformation". Continued Growth is of course the dominant image. This view suggests that, while whatever exists now may *change*, the same basic processes will operate, much as they do today. Dator points out that most educational thinking assumes this future, and actively disallows others. But, for him, if humans are to survive and thrive, this must change.

Science education has continued to see itself as having two main purposes: providing pre-professional training for the scientists of the future, working in ways that would be familiar to 20th century scientists, *and* producing citizens who are "literate" in science, and disposed to support its endeavours. The goal of continuous improvement, seeking ever more efficient ways of achieving these purposes, has been maintained.

School science has kept its traditionally strong disciplinary boundaries[7] and continued its search for ways to make its abstract, disembodied knowledge more "relevant" and/or "engaging" to students. New "content" (like the STS and/or NoS studies referred to earlier) has been added, and new pedagogies have been developed. Discussion of the importance of scientific skills, "capabilities", or "competencies" continued, largely apart from the "content" debates, and the pedagogical connections between the "knowing", "doing" and "thinking" aspects of science remain under-theorised.

Debate about why so many students are not particularly positive about school science and/or a career in science has continued, and research has increasingly focused on "teacher effects" – improving teachers' content knowledge, their pedagogical knowledge, and their pedagogical content knowledge, via new and improved pre-service teacher education and in-service professional learning programmes. School-scientist collaborations have been a focus: these were designed to "bridge gaps" in teachers' science knowledge and/or their access to up-to-date technologies and/or to provide authentic science experiences for students. Investment in "e-learning", both as a tool for communication/collaboration, and a way of providing simulated and/or authentic science experiences, has increased hugely.[8]

Because science has continued to be seen as the central plank to future economic prosperity, there has been significant investment in science education: however, it remains in "puzzle-solving" mode.

ORIENTATION 2: "SCIENCE AS INNOVATION"

The early 21st century saw an explosion of interest in the concept of innovation. Science and innovation (which were traditionally distinguished), came to be seen as strongly linked, and science/innovation came to be seen as the basis of virtually all new economic growth.[9] Science came to be valued, not as an end in itself, but for its "performativity", what can be done with it.[10]

While this shift reflected perceived economic imperatives, it was also based on an acknowledgement of changes in science in the later 20th century. First was the shift to what Ziman (2000) calls "post-academic" science: large teams of scientists, working in complex networks, on large-scale, multi-

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7 See Bernstein (1971).

8 See Bolstad *et al* (2013) and Buntting & Bolstad (2013) for recent research on initiatives in these areas.

9 For example, in New Zealand in 2012 a new "super-Ministry" was created by merging the former Ministries of Research, Science and Technology (later Science and Innovation), Economic Development, Labour, and Building and Housing. This new Ministry of Business, Innovation and Employment (MBIE) is charged with building "closer connections between the scientists and innovators who can generate new ideas and solve problems, and the business people who can translate those ideas into income and jobs." See: http:/www.msi.govt.nz/update-me/news/2012/MBIE.confirmed.

10 See Lyotard (1984).

disciplinary projects, which often have complex ethical and/or stakeholder issues. Second was the development, in the early 21st century, of new, more "open" forms of science: that is, increased use of non-expert data collection, "crowdsourcing" (Cook 2011), open sharing, discussion, and publishing of early results, and highly networked, "just-in-time" collaborations. This "Science 2.0" is highly productive: it is, according to the commentators, *the* source of innovation in today's world (Waldrop 2008, Peters 2011).[11] Alongside this were massive changes to traditional conceptions of knowledge and expertise. In the age of "big data", knowledge became "too big to know". No longer a "thing in itself", it came to be seen as existing in, and a property of, networks, *not* individual minds, or even disciplines (Barlow 1994, Castells 2000, Weinberger 2011).

These changes, combined with the policy emphasis on innovation, produced calls for change in school science. Initially these involved greater emphasis on collaborative work, "e-learning", and students participating in "authentic" science (e.g. bird counts, or collecting weather or water quality data). However, these were soon recognised as "business as usual" science education, (albeit more "authentic", and with better technology), as opposed to teaching for innovation, and the focus shifted.

Picking up on research on the conditions needed for innovation,[12] science educators began to advocate approaches designed to develop the "diversive" forms of curiosity found in very young children into the deeper, more disciplined, "epistemic" forms of curiosity that underpin mature intellectual development (Leslie 2014). These new strategies also aimed to build students' capacity to collaborate with people very different from themselves, to build deep knowledge in specific areas, and to use this knowledge in a range of creative endeavours.

While there was an apparent shift away from the traditional emphasis on the concepts and processes of science as ends in themselves, the aim was for students to develop deep knowledge in a few areas of science, to allow them to engage in "knowledge-building"[13] in areas of personal interest. However, because most people's ideas about science education's purpose did not change very much, implementation of these strategies was patchy. While there was plenty of talk about collaboration, curiosity, communication, and design thinking, these terms, like enquiry, capabilities, NoS, SSIs and so on before them, did *not* revolutionise science education: they simply became more "stuff to know" for students.

ORIENTATION 3: "POST-NORMAL" SCIENCE EDUCATION

11 See also: the OpenWetWare project at MIT http:\www.openwetware.org or the Science Commons project http:\www.sciencecommons.org.

12 These conditions are very different from those found in a typical school science classroom. Briefly, they include: opportunities for thoughtful risk-taking, trial and error, and pushing boundaries; opportunities to create, to actively produce new things; an emphasis on multi-disciplinary learning (arts and sciences together); intrinsic motivation ("play, passion and purpose"); valuing difference and unconventionality; having space to follow interests, and to develop deep knowledge in those areas; opportunities to collaborate, to work with others with very different knowledge/expertise to solve problems that all participants care about (Wagner 2012). See also Egan (2008, 2010) for a discussions of the importance of deep knowledge in at least one area.

13 "Knowledge-building" is used here in the sense described by Scardamalia & Bereiter (2006).

In the first quarter of the 21st century, the increasing likelihood of abrupt climate change[14] came to be widely accepted. The "Continued Growth" scenario became untenable and the possibility of other "images of the future"[15] had to be considered. This was deeply disruptive to educational thinking.

Environmental considerations were nothing new in education: the last half century or so had seen the development of many environmental and/or sustainability education programmes. But because these initiatives rested on many of the same assumptions as mainstream education, they were not especially helpful for supporting the kinds of change needed for the Anthropocene transition.

Fortunately, however, in the early 21st century a few theorists had started to think about the demands of the Anthropocene shift. Some emphasised the qualities *people* need to cope with postnormal times: for example, Sardar (2010) and Cilliers (2005) argued that imagination, creativity and ethical thinking are critical. The creativity theorists, on the other hand, emphasised resilience, persistence, and the capacity to "manage polarities" - the ability to hold multiple perspectives simultaneously, and the ability to shift between openness and discipline (e.g. Csikszentmihalyi 1996, Johnson 2014). Other theorists focused on new *thinking tools*. For systems/complexity theorists, while complex systems are fundamentally unmasterable (Capra 2002, Capra & Luisi 2014), it is possible to investigate elements of their behaviour via what Snowden calls "safe-to-fail probes" (Snowden 2002, 2005).

Educationists began to use systems thinking – to see "learning systems" where before they had seen individual students and subjects (e.g. Miller & Bentley 2003; Miller *et al* 2008; Senge *et al* 2000). However, science educators struggled to adapt to this new thinking. A few began to advocate teaching about science as a complex system, and/or teaching *for* complexity. Others made the case for seeing science *education* as a complex system (Falk et al 2015). However, this work was a radical departure from science education's traditional vision of itself. At this point in time it is not yet clear whether complexity thinking's influence will provoke a paradigm shift, or whether the field will continue to move slowly towards entropy and eventual death.

Each of the three scenarios above has a different orientation to the future. My purpose in constructing them was to make the point that we need to acknowledge a *range* of different possibilities for the future, and to acknowledge that there are choices to be made. However, I noticed as I was writing these scenarios that each sets out a different context for meeting *students'* needs, suggesting different knowledge/s and/or capacities accordingly. This focus on the needs of students doesn't address the "blind spots" in the discipline of science education that I argued earlier are obstructions to its development. In the last section of the paper I want to look at science education's future through a different lens, one that I think *is* a potential catalyst for change.

"SEEING THE SYSTEM?"

Bruno Latour, in his 2013 Gifford Lectures, sees the Anthropocene as heralding a major intellectual shift. Building on his long-term investigation of modernity (e.g. Latour 1993), Latour argues that we need to see nature, not as something to be tamed, or as something to be "deified", something we

14 "Abrupt" climate change is change that is so rapid that humans and other natural systems do not have time to adapt to it (IPCC 2014). According to some commentators, we can expect this within 20 years.

15 See *note 6* above.

are "apart from", but something we are deeply *engaged with*. This focus on nature, not as an "object of enquiry", but as *part* of us, something we are inextricably entangled with, needs new ways of thinking, new tools that are capable of exploring what he refers to as the "crossings", "borders" or "conversations" *between* science and nature. For Latour, the Anthropocene challenges scientists to think very differently about science – about what it *is*, what it is *for*, and what and who it should *engage* with (Latour 2013).[16]

This paper argues that the Anthropocene's advent challenges science *education* in a similar way. It challenges science educators to think very differently about what science education *is*, about what it is *for*, *who* it is for, and what and who it should be *engaging* with. Following Latour, it suggests that instead of framing science, education, and society as discrete "entities", we need to foreground the "crossings" or spaces *between* science, education, and society.[17]

Latour's emphasis on interconnectedness, entanglements, and complexity is part of the wider intellectual "turn" outlined earlier in this paper. How then, can this challenge be taken up in science education, a field dominated by its predilection for entities? In what follows I offer the beginnings of a framework for tackling this very considerable challenge. Getting "underneath" this predilection requires new thinking tools, approaches that allow us to "see the system" differently.

Some of the recent Futures Literacy literature has been helpful to me in beginning this process. Futures Studies, according to Riel Miller, is *not* about mechanistic prediction of the future, extrapolating from current trends, or managing risk. Nor is it utopian thinking, steering us toward certain desirable futures. These, he says, are the *opposite* of what Futures Studies is about. Instead,

> [w]hat distinguishes futures studies from other disciplines is their preoccupation with how we *create* the future *every day* and on this basis to analyse the prospects for change – be it one day or a century from now. … Most of futures studies focuses on exposing how the future cannot be predicted because it is contingent on choices we make *starting now*. The aim is to evoke a much wider and deeper sense of possible futures, in this sense entirely unlike the predictive traditions that depend very heavily on either continuity or on exogenous events like an apocalypse (Miller 2006, p.3, emphasis added).

Miller advocates what he calls Futures Literacies, strategies that scaffold the "anticipation" of a range of possible futures, in ways that are not constrained by our past, usually unnoticed, assumptions (e.g. Miller 2007, 2009, 2011b, 2014). As Keri Facer puts it,

> [t]his perspective changes the dominant metaphor for our orientation toward the future. Rather than envisaging ourselves walking forwards into a future in which choices are laid out before us and from which we must choose, carefully selecting paths to avoid risks and fears. Instead we might imagine ourselves walking backwards into an unknowable future, in which possibilities flow out behind us from our actions (Facer 2013, p.9).

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[16] See also: http:/www.modesofexistence.org.

[17] A possible starting point could be to acknowledge and support science education's development as a wider *system*, a complex, inter-connected network or "ecology" of different activities, which would include informal learning contexts (museums, science centers, digital media, holiday programmes and so on), as well as schools, universities and so on (see Falk *et al* 2014). Thinking about it in this way opens up a space to ask the questions Latour suggests.

But to think about and make choices for the future, we first have to be aware of the basis for our *past* choices. This, in the case of science education, seems to be a series of unconscious assumptions. We need strategies for helping us "release" these assumptions, strategies that will allow us to "see the system"—in all its complexity—in new ways.

System change involves addressing the mind-set *out of which the system arises* (Meadows 1999). This of course is no easy task. As Heifetz *et al* put it,

> Enough important people like the situation exactly as it is, whatever they may say about it, or it would not be the way it is." (Heifetz *et al* 2009, p.17).

While it is common for individuals and organisations in a system to rhetorically promote new approaches and paradigm shifts, the capacity to fully embrace and enact new ideas is often limited by existing but unnoticed or unexamined assumptions and beliefs. These hidden assumptions obstruct, or, as Kegan & Lahey (2009) put it, make individuals and organisations "immune to change". Overcoming this immunity requires us to bring these assumptions to consciousness, or, as Kegan puts it, "make them object". Kegan (who is an adult development theorist) writes:

> Differentiation always precedes integration. … Before we can reconnect to, internalise, or integrate something with which we were formerly fused [or "subject to"], we must first distinguish ourselves from it ["make it object"]. (Kegan 1994, p.326).

So: what are the "unnoticed" assumptions in science education that we need to "make object", so that they can be put up for discussion, engaged with in new ways for the "new times"? Here's my attempt to "notice" some of the more obvious ones.[18]

First science. We treat science as an "entity", something that, while it evolves, *already exists* as a "thing in itself", outside human thought (and values), and, therefore, "coming before" education (and society). While there is now a large body of work (e.g. in the philosophy and sociology of science) showing that science, like all the other disciplines, is a social construction: that is, that it evolves alongside, and embedded in, our social systems, there is another, different point to be made here. The debate over which—science, society or education—"comes first" (and therefore structures whatever comes next) just reinforces our predilection for entities. Seeing our way out of this rut requires us to ask different questions: How are science, society, and education *inter*-connected? How do they depend on each other? How do they influence each other? How do they construct each other? How do they *talk to* each other? What does asking these kinds of questions tell us about the system they are part of? What new ways of looking at it are opened up? What new "images of the future" become possible?

Second education. We treat education as the process of accumulating conceptual and practical knowledge, which develops the mind, and prepares people for the world of work and for citizenship. It takes place in specialised institutions, and involves following a pre-set curriculum, assisted by teachers. But is this kind of education, already being called into question, likely to continue? Other

[18] This list is an attempt, not to *define* these ideas, but to capture their discursive functioning in science education.

learning opportunities are already available - via the new knowledge networks, invisible colleges, not-school and so on, and preparation for the world of work is unlikely to remain a key function. Electronic devices will render traditional practices redundant - teaching will have to become something other than the mass instruction of students, through pre-determined steps, to mastery of topics that are of little interest to them. What *should* education's goals be, as we transition to the Anthropocene? How, if at all, could education support people to work well with complexity, uncertainty and contradiction? How, if at all, could it support people to work well with *each other*?

Third, society is also treated as an entity, as something that has always existed. Yet it too is a contract of modernity. Modern mass education was supposed to produce the kind of society we want, to create the "glue" that holds it together. A great deal of what is taught and how it is taught has this purpose. But maybe society will be "held together" differently in the future. Or maybe holding it together won't be possible in an age of "filter bubbles" (Parisier 2012) and steadily increasing inequalities.

Four, we treat the future as if it were a single "something", and we treat it as if it already exists. As Miller, Facer and others point out, this closes down the possibilities for thinking and acting to create it.

The above list is obviously just a beginning: my point here is that "noticing" these assumptions, bringing them to consciousness, is a necessary precursor to change, to seeing science education differently for the future. If we want there to *be* a future for science education, I think we need to start seeing its purpose as being to support different ways of defining, envisaging, constructing, and creating the future - in students, but, *before this*, in *ourselves*. Even considering this has profound implications for what we can see, and what we can do - now, in the present (Miller 2011b).

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