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Science Education Futures. Science Education as if the Whole Earth Mattered.

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Abstract.
In 1990 a gathering of ecopsychologists took place at the Harvard Centre for Psychology and Social Change to participate in a conference entitled "Psychology as if the Whole Earth Mattered". They concluded that "if the self is expanded to include the natural world, behavior leading to destruction of this world will be experienced as self-destruction" (Roszak, Gomes, & Kanner, 1995). I take this idea into the realm of science and science education which I suggest requires a reconfiguration and extension of science into a new inter- and trans-disciplinary realm of sustainability science with implications for renewed pedagogies of science in schools and universities. Such a changing perspective requires greater vision, creativity and imaginative approaches to address the problems currently facing the planet and the future of humanity. This paper provides an overview of a journey in science education over the years covering a range of views around science: starting from what we might consider to be the idea of modern science and how that science has been transformed into "big science" and "techno-science". Further, in the current era of the Anthropocene (Steffen, Crutzen, & McNeill, 2007) it can be argued that such approaches to science need to be reformed to take account of ideas such as post-normal science (Funtowicz & Ravetz, 1994), sustainability science (Clark & Dickson, 2003) and holistic science (Bohm, 1980; Goodwin, 1997). Using the concepts of planetary boundaries (Rockström et al., 2009b) and doughnut economics (Raworth, 2012, 2017) as a framework, consideration is given to what this might mean for science education futures.

Key words. pedagogies of science, techno-science, planetary boundaries, doughnut economics

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Introduction: Science, Society and the Age of the Anthropocene

It has become apparent in the closing years of the 20th century and the opening of the 21st, that a crisis in science, encompassing the "roles and social functions of science" (Saltelli & Funtowicz, 2017, p5) has progressed hand in hand with another crisis, that of the overstepping of the 'planetary boundaries', (Rockström et al., 2009a, 2016; Steffen et al., 2015) thereby resulting in an unsafe operating space for humanity. We are now said to be living in the Anthropocene, a term coined by Eugene Stoermer and popularised by Paul Crutzen, put forward to suggest that we have entered a new epoch characterised by the human impact on the planet (Crutzen & Stoermer, 2000). This is an epoch in which human beings and their societies have become a global geophysical force capable of creating global level changes in the biological fabric of the Earth; the stocks and flows of major elements in the planetary machinery such as nitrogen, carbon, phosphorus, and silicon; and the energy balance at the Earth's surface" (Steffen et al., 2007, p614).

Such are these crises that many, very prominent, scientists have passed comment on them. Jane Lubchenco, for example, in her presidential address to the American Association for the Advancement of Science stated:

> *The world at the close of the 20th century is a fundamentally different world from the one in which the current scientific enterprise has developed…" and "…Business as usual will not suffice* (Lubchenco, 1998, p492).

Just a few years later, in the new millennium, Peter Raven, the then president of the AAAS, suggested that "We need new ways of thinking about our place in the world and the ways in which we relate to natural systems in order to be able to develop a sustainable world for our children and grandchildren" (Raven, 2002, p958). More recently, the eminent physicist, Stephen Hawking, suggested in his UK Reith Lecture in 2016, that "most of the threats we face come from the progress we have made in science and technology", (Hawking, 2016, p7). Hawking went on to suggest that we will have to recognize the dangers and control them. However, the Earth is a complex open system and predictability and control in a complex open system is not possible with any certainty (Solé & Goodwin, 2000). This has implications for how we conduct science and how we use the knowledge gained from science. While modern science is held up as the apogee of modern civilization and has achieved a certain hegemony in Western culture, thought and institutional practice, this very hegemony has resulted in the "delusive belief that science and only science could find proper answers to any and all questions that human beings might ponder" (Bauer, 2004, p643).

There are many commentaries from the field of science studies which have sought to articulate the changing nature of science in society. All these perspectives indicate that science has moved away from what might be considered as the more traditional, historical idea of science, what Gibbons et al. (1994) call Mode 1 knowledge production, or Ziman (1996) calls "academic" science. The new forms of knowledge production are much more distributed, interdisciplinary and applied, often with connections to industry and commerce. Such new configurations of science, Mode 2 (Gibbons et al, 1994), post-academic (Ziman, 1996), the Triple Helix of university – industry – government relationships (Etzkowitz & Leydesdorff, 2000; Etzkowitz & Zhou, 2006) have resulted in complex, larger scale and high impact forms of science knowledge production.

Science and Corporate Interests

The term "Big Science" (Weinberg, 1961) refers to the way in which, following the second world war, the scientific enterprise developed a new form of working which required large budgets, often provided by governments and linked to military and energy research, conspicuous staffs, big machines and big laboratories. The number of scientists employed on research projects grew from the small teams in research departments in institutes or universities into several hundred individuals working on big projects, such as those at the CERN particle accelerator in Switzerland. As described by Aranova, Baker, & Oreskes (2010), academic research had increasingly become bonded to big government and big industry. This had transformed science from an individual initiative into a collective enterprise, requiring large interdisciplinary government-funded teams of researchers as a major feature of this novel organizational form of scientific research.

While there has been considerable academic theorisation in the field of science studies, which has often created tension between the idea of the "hard facts" of science and the idea of science knowledge being, at least in part, a socio-cultural construction (Longino, 2002) perhaps some of the ideas about how we are in our current predicament can be extrapolated from examination and compilation of different aspects of these theorisations.

So on the one hand the crisis in science is a result of the institutional entrenchment of the corporate organization of science as it is currently structured, which has given rise to what Bauer (2004) calls *knowledge monopolies* and *research cartels*, controlled and funded by large multinational interests. On the other hand, the crisis is, arguably, also caused by an outmoded way of thinking in science which, while very successful at certain local levels, when applied to global issues and planetary dynamic systems, fails and, in fact, has the potential to cause catastrophic harm to ecosystems and human populations, particularly when tied to corporate global developments.

In summary, what we have in science and technology is a greater and greater alignment between the sciences and industry, often supported by governments. The direction and choices made with respect to the sciences is largely dictated by the needs of industry, with, perhaps, universities taking on an increasing role in commercialisation ventures related to the production of scientific knowledge. Of course, this is an oversimplification but it essentially is the underpinning driving force behind the undertaking of science and the underlying reasons for encouraging what has come to be known as STEM education in schools. With the acronym STEM, a clear indication is given of the applied nature of science education, privileging those subjects which may be associated with economic and industrial ventures (The Scottish Government, 2016). Coincidentally, and almost to prove a point, the title of a seminar organised by Scotland Policy Conferences in 2018 is "Next steps for STEM education and training in Scotland: widening participation, improving delivery and *meeting the needs of business*" (Scotland Policy Conferences, 2018). Thus the way in which science has been conducted in the post-war period has been largely for the benefit of industry and global enterprise, together with resultant social benefits, but at an environmental cost which has been largely ignored. While this form of scientific knowledge production remains the dominant world paradigm, there is little incentive from industry and governments to critically examine the content and purpose of science education. What is important, therefore, is that education needs to focus on questioning this dominant economic world view, replacing it with an ecological world view and a science education which is commensurate with such a world view. Unlike an economic world view, which mentally disconnects human progress and economic growth from the biosphere, an ecological world view recognises that humanity is deeply intertwined with, and is part of, the natural environment, there is no separation (Folke et al., 2011; Zweers, 2000). As such we need to consider what is important now and for the future, and to consider the type of science education, its contents and objectives, required to address these. Later I set out a provisional framework as a foundation for exploration, discussion and development. Before this, however, there is a need to examine the philosophical and practical foundations on which modern science has been built.

The Limits of Reductionism

Perhaps one of the fundamental aspects we must recognise with respect to current, modern, science is the foundation upon which it has been built, the notion of reductionism. Reductionism is, quite simply, the idea that the scientist can focus on the parts of any object, process, or system and by understanding the parts it is possible to assemble the parts to understand the whole. In many spheres this is acceptable and practicable but only if the phenomenon under investigation is a simple, mechanical or closed system. To that degree reductionism has been incredibly successful in producing many of the materials and processes that we take for granted today. However, there is a growing recognition of the limits to reductionism, "…reductionism is inadequate as the primary explanatory framework of science. Progress in understanding natural phenomena … involves grasping relevant aspects of whole systems" (Solé & Goodwin, 2000 p.19). Recognition of the limitations of reductionist science is not new, many scientists have recognised this and have suggested more systemic approaches (e.g. Katagiri, 2003; Lucadou & Kornwachs, 1983; Regenmortel, 2004). However, Bortoft (2012) critiques the claim made by systems thinkers that it is holistic, suggesting "it is in fact much more reductionist in practice than many of the optimistic pronouncements about it would lead us to suppose" (p13). Such a view of supposedly holistic approaches, such as systems biology, are not unique to Bortoft, with other critics also pointing out that systems approaches often fall short. Joyner & Pedersen (2011), for example, while applauding systems biology for recognising the limits of reductionism suggest that it "continues to fail to recognize that a variety of integrating functions between cells, organs, systems, the entire organism and the environment are required to generate a fully functional and highly adaptive animal" (p1020). Bortoft addresses this limitation in systems thinking and offers a different approach to wholeness, which will be considered later.

A Multiplicity of Legitimate Perspectives

A result of the gradual recognition of complexity in Earth systems is that it has led to a realisation that "normal" science (Funtowicz & Ravetz, 1993) cannot be privileged when it comes to decision making in policy processes around socio-environmental issues. Such recognition led to the development of the concept of post-normal science by Funtowicz & Ravetz (1993). In post-normal science the two attributes of systems uncertainties and decision stakes are used to determine the type of science that can be used. When either attribute is high, then the traditional methodologies of modern science are ineffective and, in those circumstances, an 'extended peer community' is required in order to provide greater quality assurance of scientific inputs to the policy process. Such an extended peer community consists of all those with a stake in the issue. In this way post-normal science can provide a path to the democratization of science. Such ideas are rarely, if ever, encountered in a science classroom or science lecture hall.

However, the idea of sustainability science, which seeks to understand the fundamental character of interactions between nature and society, is perhaps starting to become more mainstream. In order to do this, such a science must encompass the interaction of global processes with the ecological and social characteristics of particular places and sectors, and research will have to integrate the effects of key processes across the full range of scales from local to global (Kates et al., 2001). There is clearly an overlap with ideas contained in post-normal science, although the fundamental difference is that post-normal science is predominantly focussed on the processes that science and policy must engage in when dealing with decision making in complex socio-scientific/socio-environmental issues, whereas sustainability science is more focussed on the way in which science itself is conducted when grappling with such issues. As Kates et al., (2001, p641) state:

> *sustainability science that is necessary to address these questions differs to a considerable degree in structure, methods, and content from science as we know it*.

The implications for science education

So, if there is a need for a practicing science that "differs to a considerable degree in structure, methods, and content", to what extent is this being addressed in core science courses in schools, colleges and universities? Certainly there are moves in this area with a number of courses on sustainability science, very often at Masters Level, being provided in higher education institutions around the world.

However, arguably, there is still little indication of these changes occurring at school level or undergraduate science degree courses. Perhaps what is important to note is what Clark (2007, p1737) states with respect to sustainability science as "a field defined by the problems it addresses rather than by the disciplines it employs". From the recent thinking in post-normal and sustainability science, with recognition of complexity and the intractable interconnectedness of socio-environmental systems, I would suggest that there are a number of issues which need to be addressed in science education. One is the "how" of science and another is the "what" of science.

Towards new visions for Science

According to Bortoft (2012) the current predicament we find ourselves in on the planet is largely as a result of our approach to the production of scientific knowledge. This approach is a Newtonian mechanical philosophy and the mathematical physics of nature; and is a Verbal – intellectual (computational, representational) approach which subjugates the sensorial and experiential. It situates science "outside" of Nature; and is built on a foundation of Cartesian dualism. While some alternative approaches to science, such as the sustainability science already mentioned (Kates et al., 2000), which recognise our situatedness in nature, are becoming more mainstream, others such as Goethean and holistic science (Bortoft, 2012; Goodwin, 1997; Seamon, 2005) still remain at the fringes. It can, however, be argued that some of the principles they advocate are important in developing a new sense of connectedness and embeddedness within the natural world, as well as offering more engaging and enactive forms of science education. At the same time, it should be stated that adopting more holistic and phenomenological approaches to science does not mean rejecting in its entirety reductionist approaches. Each have their place. As Maurer (1999) stated with respect to understanding ecological systems:

> *this is not to say that reductionist science cannot help scientists understand ecological systems. I am simply arguing that reductionist science alone will not suffice* (p7).

Reductionist approaches in science are not appropriate for the study of global environmental issues, perhaps an argument to be pursued is the degree to which we require reductionist science at all. Such an acknowledgement recognises the inherent unpredictably of complex open systems and the capacity for such systems to reach a tipping point when they will "flip" into a different configuration. Such a "flip" can be significantly, and possibly dangerously, different from the system it emerges from. The science of complexity has been described by Goodwin (1997) as a holistic science, which seeks to describe the properties of complex wholes. Such an understanding is very different from the Newtonian mechanistic principles on which modern science has been built. We thus see that, in sustainability and holistic science, there is a need to move from a mechanistic to a holistic perspective, which entails a move from seeing phenomena as a simple linear chain of events to a vision of complex, non-linear phenomena, which are inherently uncertain and unpredictable. We also need to recognise that human systems are inextricably bound up within natural systems and human beings are embedded within their environment and not detached and separate from it. Sustainability science, therefore, needs to focus on the dynamic interactions between nature and society "with equal attention to how social change shapes the environment and how environmental change shapes society" (Clark & Dickson, 2003, p.8059). Solutions to such problems need to be ''coproduced'' through close collaboration between scholars and practitioners, in a way similar to the idea of the extended peer community suggested by Funtowicz & Ravetz (1993).

We can thus see that there is a move within the sciences themselves to begin to recognise different ways of approaching knowledge about the world. Ways which recognise that the Earth and the systems upon it do not behave in the way suggested by Newtonian and Cartesian mechanistic science, although their principles may still have some role in future science.

However, it is important to recognise that modern science, as currently practiced is only one way of knowing. The direction taken by modern science was only one possibility, the choices made at the onset of this modernity opened the door into the way that followed, but at the same time it closed the door to other possibilities (Bortoft, 2012). Or, as Hutchins (2010) suggests with reference to Bateson's view that boundaries should not be placed across important communication lines in a network, something which happens often in reductionist science, "Every boundary placement makes some things easy to see, and others impossible to see. The danger of putting boundaries in the wrong place is, as Bateson warned, that doing so will leave important phenomena unexplained, or worse, inexplicable"(p706). What future science must do is to open up the doors to other ways of seeing so we begin to approach knowledge and the production of knowledge in a new way. *"A change in the way of seeing means a change in what is seen"* (Bortoft, 2012, p143). It can also be argued that in order for there to be a change in the way of seeing, scientists must recognise that there is no real separation between themselves and the phenomena that they are investigating. This process, which Goethe called 'delicate empiricism' (Zarte-empirie) is described by Naydler (1996, p71):

> *The Goethean scientist seeks to participate in the objects investigated to such a degree that the mind makes itself one with the object, thereby overcoming the sense of separateness that characterises our normal experience of ourselves in relation to the world.*

Such a recognition begins a transformative process for the scientists involved. Many authors have suggested that Goethe's vision of science offers some prospect for a renewed approach to science (e.g. Amrine, 1998; Bortoft, 2012; Franses & Wride, 2015; Hoffmann, 1998; Seamon, 2005). Goethe suggested that direct experiential contact was the basis for scientific generalization and understanding, but that the experience was only the beginning of a rigorous scientific process.

Science Education

While a crisis in science caused by the close association between corporate business and the scientific community has been posited, at the same time it has also been suggested that there is a crisis in science education which emerges every few years (Aubusson, Panizzon, & Corrigan, 2016; Gilbert, 2016). The claimed crises in science education usually focus on the perceived reduction in young people's science knowledge and interest in science, although the legitimacy of such claims is disputed (Gibbs & Fox, 1999). As suggested earlier, this crisis usually relates to the apparent drop of young people's interest in science subjects, and their continuation into higher education or careers in the sciences. In the UK, for example, the House of Commons Committee report on Science Education (HCSTC, 2002) in 2002 described the science provision as being required to provide a general science education for all but also to inspire and prepare some for science post-16, stating that "it does neither of these well" (p.5) with most science taught at ages 14–16 having "remained largely unchanged for decades" (p. 16). This apparent drop in interest is seen as problematic in policy areas largely because of the perceived importance of science for economic competitiveness, as well as for quality of life (HCSTC, 2002). However, while the crises in science education often focus on young people's performance in science, or their inclination to go further in science and pursue careers in science, the actual science contained within science education is very often not subjected to close scrutiny. What is rarely recognised is the connection between the role that science plays in the economic sphere and the growing impact that this is having on the planet and on human societies. Others, however, have recognised that the way in which science is introduced in schools today is not necessarily conducive to nurturing a way of thinking which recognises the complexity of environmental problems, nor offers a way of thinking which can contribute to dealing with those problems. Ashley (2000), for example queries whether science is an "unreliable friend to environmental education", suggesting that "Almost all pupils…are presented with a view of science that is still largely influenced by logical positivism, reductionism and the 'value-free' thesis. It is, furthermore, a curriculum that is driven primarily by the goal of selection for university entry" (p275). Carter (2005) points out that the complexities of our increasingly globalised world and technoscientific society are not well elaborated in school science education, a point dealt with by Gray & Colucci-Gray (2014). Even Aubusson et al.'s (2016) consideration of science education futures does not deal with this in any depth. However, Gilbert, (2016) does recognise that it is perhaps time to reconsider this, stating, in relation to our fossil-fuel based existence, 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." (p.188).

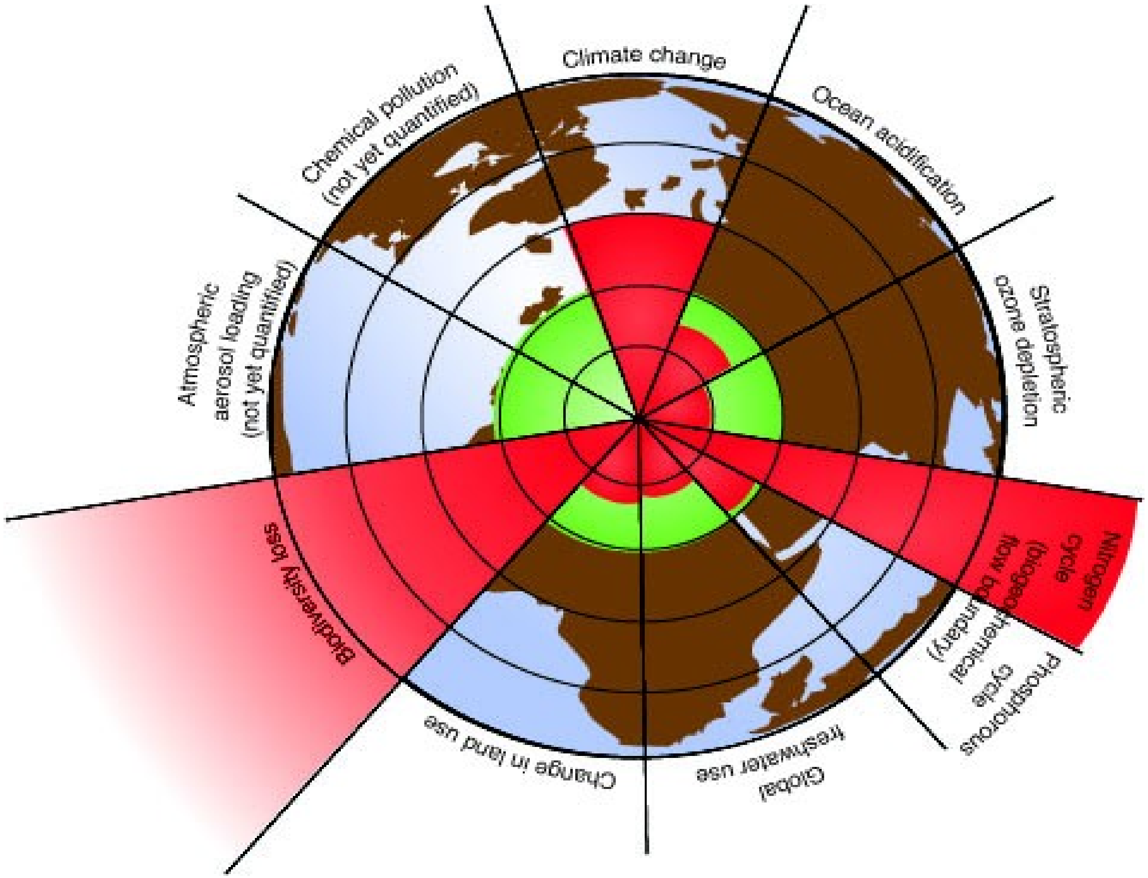
Similarly Osborne's (2007) consideration of science for the twenty-first century, while having much to commend it, and recognising that science education is important in addressing global issues, focuses very largely on classroom based pedagogy and argumentation in science. Much of previous literature in science education still regards science as verymuch a conceptual, "in the head", process and largely ignores recent work on embodied cognition and socio-materiality (Gallagher and Lindgren, 2015), which, it can be argued, may prove to be a critical factor in developing positive environmental attitudes, enhanced learning and engagement with science.

What visions for Science Education Futures?

In the preceding paragraphs some of the current critiques of modern science have been outlined, along with the need to adopt practices in science which acknowledge and integrate other forms of knowledge and other approaches to generating knowledge and understanding of the world around us. Adopting new thinking in science education, which recognises the complex, interdependent nature of the planetary cycles, will help in developing new approaches to addressing problems at the planetary scale. Thus, the following paragraphs will look at what the implications of such recognition might be for a science education futures.

For science education to be relevant and appropriate to current concerns it must do three things. It must cover the science that is necessary to understand current planetary problems, which includes understanding ideas around complexity. It must recognise that science is only one way of gaining knowledge and should be able to engage with other forms of knowledge in dealing with complex problems; it must incorporate current understanding about cognitive process and associated pedagogies to enable learners to effectively engage with and understand the issues and phenomena they are investigating, as well as their own way of investigating, observing and making sense of the inquiry.

With respect to necessary scientific knowledge required to understand issues around the Earth systems, the planetary boundaries model proposed by Rockström et al., (2009) provides a robust framework within which many of the key concepts of science can be explored. This model identifies nine of the planet's bio-physical subsystems or processes which define the safe operating space for humanity with respect to the Earth system. It is important that these boundaries are not transgressed, yet we have already overstepped the safe operating space for three of these boundaries (see Figure 1).



“Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.” (Rockström et al., 2009a, p472)
Credit: Azote Images/Stockholm Resilience Centre

It may be felt that the planetary boundaries model does not cover all the areas of science of interest to the many different disciplines, but it can provide a good working framework for many, if not most areas of science in schools. Many key concepts already dealt with in school science, such as the carbon, nitrogen and water cycles can be reframed in relation to the planetary boundaries model to make these concepts more relevant to young people’s lives and to help them in understanding the importance of these systems. There are many such issues that can be covered in this respect, issues such as air quality in cities, plastic in the oceans, the impact of industrial agriculture and meat based nutrition.

If the planetary boundaries model is taken as a starting point, it can then be elaborated in many socio-scientific issues through development and engagement with social sciences using the “doughnut” model first proposed by Raworth (2012) and subsequently further developed and elaborated to the current model in Figure 2.

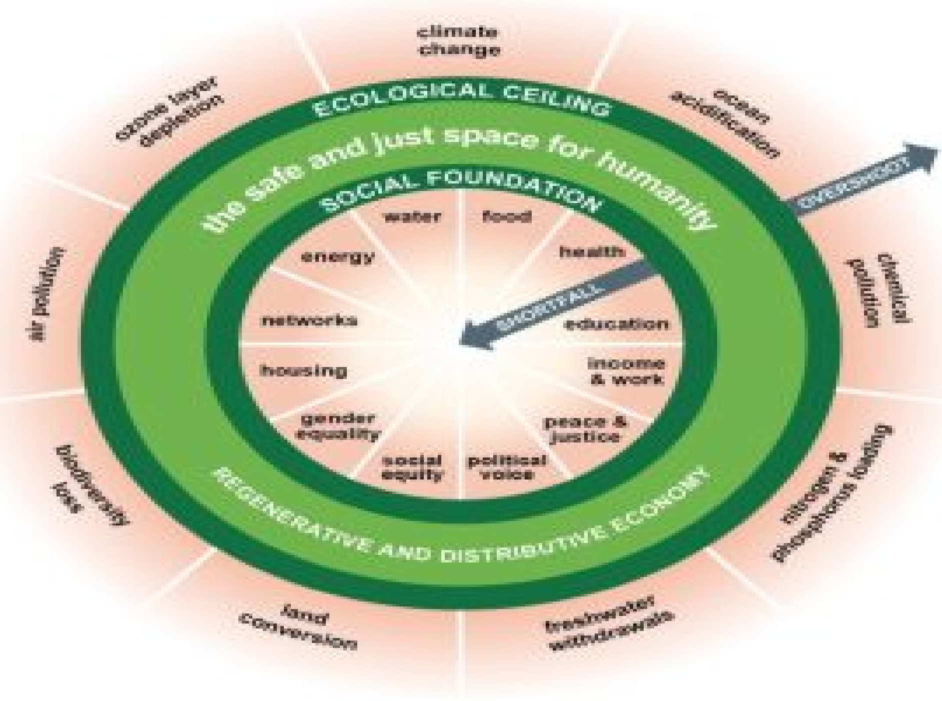


Figure 2: The Doughnut of social and planetary boundaries (2017)
Source: https://www.kateraworth.com/doughnut/

In this model, the two key features consist of an outer environmental ceiling of nine planetary boundaries, as described above, beyond which lie unacceptable environmental degradation and potential tipping points in Earth systems. We must not surpass this ceiling. The inner social foundation of the model is formed from twelve dimensions derived from internationally agreed minimum social standards, as identified by the world's governments in the Sustainable Development Goals in 2015. It is suggested that society should be structured such that no-one falls below this social foundation. The space between the social and planetary boundaries is an environmentally safe and socially just space in which humanity can thrive.

We need a science education which focuses on relevant science that bridges the knowledge frontiers required by a modern economy, but also primarily provides a foundation for current and future generations to understand the safe operating space required by humanity on a finite planet. Such a science education will also address the socio-environmental problems that the sciences are, at the very least, implicated in and potentially exacerbate. Such a science education is different from the 'Big ideas in science' approach, put forward by Harlen, (2010; 2015), which attempted to set out principles that should underpin the science education of all students throughout their schooling, and takes the position of more openly addressing the earth systems approach but linking in with socio-environmental issues. In this respect it is similar to the politicized, issues-based curriculum proposed by Hodson, (2003) which, he suggests should focus on seven areas of concern: human health; food and agriculture; land, water and mineral resources; energy resources and consumption; industry; information transfer and transportation; ethics and social responsibility.

The doughnut model provides a good basis, I suggest, for considering the content of future science education programmes: a science education that deals with real-life issues, planetary stability and social and environmental justice. However, as well as a model for content, we also need to consider the way in which pedagogies are constructed.

Body, Mind and Nature in Science Education. Renaturing[1] Science Education.

As outlined above there is clear evidence from the literature around science studies and science education, that both leave much to be desired when it comes to engaging with planetary processes and socio-environmental impact of human activities. There is now a growing body of literature which provides further argument for a different approach to science education. The key element of what might be a renewed pedagogy for science education is a much greater understanding of the complex and dynamic interdependence of the body, the mind and the environment.

Much of modern science, and thus modern science education, has been foundational on the idea of the computational model of cognition i.e. that cognition rests entirely in the brain and results from a representation of the external world being present in the working mind. The second aspect is that scientists, and thus students of science, are separate from the external world which can be viewed objectively, from a neutral, value free position. Both of these foundational ideas are now subject to increasing critique emanating from a much great understanding of the relationship, and interdependency of our bodies, minds and the environment in which we are all embedded.

One aspect of this is the way in which our brains, particularly at younger ages, are shaped and moulded by the experiences we have of the world we move around in. With respect to children's development, it is important to acknowledge the changing, and highly urbanised, environment that most youngsters are now growing up in. It is more than ten years since half of the world's population migrated to urban environments with the current figure at 54% (World Bank Group, 2018) and with a projection for that to increase to 70% by 2050 (UNESCO, 2016). This figure has already reached 73% in Europe and is projected to rise to 84% in this period (UN Habitat, 2008). Arguably, one result of this increasing urbanisation is a sense of disconnectedness from the natural world, a distancing from the fabric and energies that actually sustain us on the Earth (Ives et al., 2017; Nisbet, Zelenski, & Murphy, 2009). Thus, as children become less exposed to natural environments, and more exposed to urban life and digital technologies, so their perspectives, values and attitudes toward the natural world will be changed. As Puk (2012, p5) states:

> *The developing mind is being stimulated on a daily basis overwhelmingly by technology, by media, by transportation, by books and by words rather than by wind in the trees, the smell of the earth after a rain, the ever changing movement of water, the sound of silence in quiet meadows and the awe and majesty of ecological systems.*

Such an interdependency between body and mind was noted around a hundred years ago by John Dewey, who recognised the inextricable link between body and mind, using the term "body-mind":

> *The world is subject-matter for knowledge, because mind has developed in that world; a body-mind, whose structures have developed according to the structures of the world in which it exists, will naturally find some of its structures to be concordant and congenial with nature, and some phases of nature with itself* (Dewey, 1925, p225).

Of course, it is clear from Dewey's words that the body-mind does not exist in isolation from the environment it finds itself in, since "mind has developed *in* that world", with the body being the mediator between the external world and the inner mind. This might appear self-evident but has largely been ignored by classroom-based pedagogies during the history of schooling, perhaps more so in many of the sciences which, given that they are essentially concerned with understanding the world and

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[1] Renature: to restore (a denatured substance) to its former, natural state. In this context we can think of science as the study of *nature*, of understanding the natural world. While essentially this is still a definition of science the use to which science has been put is more for economic gain than for planetary stability. Refocusing on nature may help to restore that balance.

nature, should actually be more engaged with experiences in the world. However, views of cognition have been largely dominated by the computational model of the mind, in which the brain constructs representation of the world inside the head, the body not playing any significant part.

Now, however, progress in neurocognitive sciences, as well as considerable developments in the philosophy and psychology of mind, have led to a much greater understanding of the role of the body in cognition, embodied cognition. Gallagher and Lindgren (2015) explain that cognition, as enactive and embodied, does not take place, as traditional cognitivist views have it, 'in the head' as some form of symbolic representation of an external world, but is rather a dynamic set of interactions between brain and body and between body and environment. While individuals are autonomous autopoietic systems, they are always systems, they are always 'structurally coupled' to their environment (Thompson, 2007) and 'structural coupling' refers to the history of recurrent interactions between two or more systems that leads to structural congruence between them (Maturana, 1975; Maturana & Varela, 1987). In other words, it is the interaction of body-brain-environment as inseparable units, thus the hyphens, which is central to cognition, to knowing. 'They produce each other, and thus are linked by a radical form of co-dependence' (Bocchi & Damiano 2013, p.123). Gallagher & Bower (2014) provide further elaboration of the idea of enactivism, which is an extension of embodied cognition. In enactivism the link between body and mind is further elaborated by the dynamic coupling of the body-mind with the environment. In other words cognition arises through a dynamic interaction between an acting organism and its environment, it does not happen through simple computational representation in the brain. However, as Gallagher and Bower (2014) suggest, an account that focuses only on sensorimotor contingencies falls short due to its neglect of the relevance of the affective domain. These aspects will include "proprioceptive and kinaesthetic aspects—factors that should be of high interest since they derive from movement and contribute to one's practical grasp of sensorimotor contingencies" (p234). Thus, it is not only the sensory-motor interactions with environment that are important in cognition but also the affective dimension, an area that has been largely ignored in science education (Alsop, 2005).

So, we begin to see that there are more recent ideas in cognition that may make a significant contribution to future pedagogies in science education, some of which have made their way into some classrooms already, but what is required is much more research and development in this area. Existing research already suggests that whole-body engagement, framed by enactive metaphors, in other words metaphors that we put into action or that we bring into existence through our action, rather than metaphors which "sit on a page", can improve learning outcomes in science, mathematics, and other subjects (Gallagher and Lindgren, 2015, p391).

Recognising that cognition is firmly linked to our lived experiences and perceptions of the environment in which we move around, leads to the inevitable conclusion that the type of environment we find ourselves in is going to play a significant role in how we see the world around us. So young people growing up in a heavily urbanised city, exposed to primarily digital technologies, smart phones and TV screens, with little access to green space, are going to have a significantly different view of the world from those who have more ready access to natural environments and whose exposure to techno-scientific developments is more controlled.

Greater engagement with natural environments, it can be argued, is thus an essential requisite for all sciences at all stages of education. All the sciences can potentially have a significant impact on the planet, as has already been demonstrated, from chemists and biologist through to engineers and physicists. It is, therefore, essential that all children and young people at all stages of education, are provided with the opportunity to become deeply engaged with the natural environment. It is only through this profound engagement that they will gain a deeper understanding of their place in that natural environment. Referring back to the beginning of this paper, and the need to expand the self to include the natural world, in order to do this we must begin to open our senses to those aspects which current scientific practice shuts down, what the author elsewhere has called "renaturing science" (Gray & Sosu, 2018)

Perhaps one way of doing this is to learn from Goethean science. While Goethe is primarily known for his literary works, he was also intensely engaged in the scientific study of a range of topics such as "plants, colour, clouds, weather, morphology, and geology" (Seamon, 1998, p1) and his approach to science, which was both intuitive *and* rigorously systematic, has been suggested as being "a valuable means for fostering a deeper sense of responsibility and care for the natural world" (Seamon, 2005, p.86), thus linking back to the idea in the opening paragraph, the necessity to nurture a more caring attitude towards the world that we are part of. This is something which, it can be argued, Goethean science attempts to do. Goethe's approach to scientific study is unusual in that it seeks to draw together the intuitive awareness of art with the rigorous observation and thinking in science (Seamon & Zajonc, 1998) and has been described as a phenomenology of nature (Bortoft, 1996). Such an approach is as much about the experiences of the scientists themselves as it is to do with the phenomenon under investigation. As described by Amrine (1998):

> *Goethe's scientific ideal is to allow oneself to be transformed in following the transformation of the phenomenon….the ultimate aim of science is nothing other than the metamorphosis of the scientist. (p.37). Essentially what Goethe did in his approach to science was to put sensory experience first rather than the mathematical modelling* (Bortoft, 2012).

Bortoft (2012) also describes his Goethean approach to science as a dynamic way of thinking, which is neither simply based on a systems approach, which acknowledges the structure of open systems and complexity, nor on the reductionist approach used in modern science which reduces all phenomena to the parts in an attempt to understand the whole. Bortoft uses the hologram as a metaphor where the whole is contained in the parts and the parts make up the whole. In order to truly understand we must find a holistic approach which requires a dynamic way of thinking that is dependent on understanding the relationship amongst the parts, " any entity is only what it is within a network of relations" (Bortoft, 2012) or as Bateson (1972, 2002) suggested "the pattern which connects".

Goethe's emphasis on the phenomenological experience as the starting point for scientific exploration, and intuitive perception, does not diminish the rigorous scientific approach that he used in his method, but it does indicate the unique connection that Goethe sees between science and art and its importance for the study of natural phenomenon:

> *… the link between art and science can provide a key to understanding Goethe's form of 'nature study' as a new ecological discipline in our time* (Hoffman, 1998, p 129).

There is thus a need to consider the contribution that the arts can make to science and science education.

From STEM to STEAM.

It is this link with art which has recently become more prominent, although perhaps for different reasons. The term STEM, originating in the USA, has been used to address concerns about apparent lack of engagement in the sciences and also in relation to the perceived need for global economic competitiveness. In the USA the Committee on Science, Engineering, and Public Policy placed greater emphasis on STEM (Science, Technology, Engineering and Mathematics) as a response to the poor performance of students in Science and Mathematics (NASCSEPP, 2005) . It also specifically linked future national prosperity with having enough STEM graduates to support the STEM workforce and, having enough STEM teachers to teach STEM subjects to the next generation (Colucci-gray et al., 2017). Incorporation of the "A" into STEM to create STEAM, again arose largely from an economic imperative, as a means to engage young people in STEM careers in order to revitalise the US economy, however, it is also suggested that such integration can be used to reconfigure science for a more sustainable future (Colucci-gray et al., 2017). As van Boeckel (2009) states: ""Art, through engaging the senses, can be a unique catalyst in developing a "sense of wonder" about nature." (p1) and "Through art, we can see and approach the outside world afresh. Art can hit us unexpectedly, catch us off-guard, and sometimes provoke us. This estrangement or defamiliarization is an important quality of art." (p2). Thus, there is an important quality to art which requires us to look afresh at the world and can move us to see things in a different way, which is complementary to the scientific way of looking at things. Hoffmann (1998), in elaborating the unity of science and art in Goethe's work as a new ecological discipline, argues that "*both* science and art are necessary to obtain a full picture of reality" (p167). There is not space enough here to elaborate on the many dimensions of STEAM, which is a contested and not clearly defined concept. However, the recent work by Colucci-gray et al. (2017) provides a significant contribution to elaboration and discussion in this area, as well as opening up avenues for further research in science education.

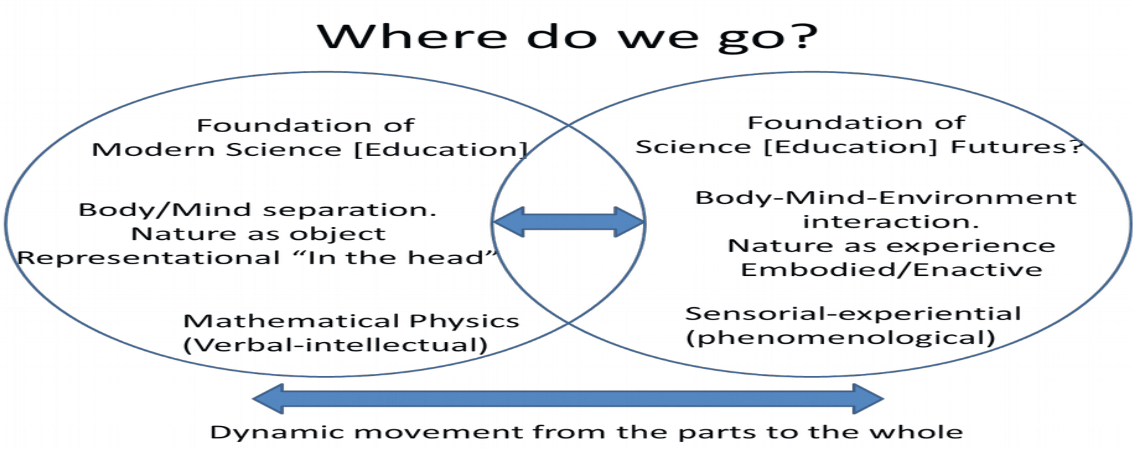
From OIL to SOIL.

In the current age of the Anthropocene, where we are beset by global problems primarily linked to industrial development and commercialisation around oil-based energy and products, and the ubiquitous digital network, it is worth referring back to the statement by Gilbert (2016) introduced earlier. If we accept, and I think most people do accept, that carbonised modernity, as we know it, is coming to an end and that we can manage to resolve the problems it has created, then we must consider what form science education takes to prevent such global problems reappearing in future. This article has tried to address some of the issues and propose some areas that we can look at to try to re-orientate science education away from an economic perspective to a more eco-logic perspective. There has to be a renewed focus on the purpose of science education, which, it can be argued, has to be about providing a much greater understanding of the interconnectedness of global systems and our embeddedness in those systems. For too long science and science education have acted as if we can safely situate ourselves outside of Nature, when in fact we are an embedded part of it. This must be recognised and science education reconfigured to reflect that. The North-East of Scotland is one of the leading centres for oil and gas developments in Europe and, interestingly was also home to one of the early pioneers of environmental education, Patrick Geddes. Geddes was very much of the mind that we need to get young people outside to experience nature and we should keep his words in mind as we move forward:

> *…the advocates of science have not succeeded in fully adapting their studies to the growing mind…too much the advocacy of "Natural Science," and too little an opening of the classroom into Nature itself, a leading out of the pupil into direct and first-hand acquaintance with her varied and living reality...* (Geddes, 1902, p.527). …
>
> *Nature is thus the ultimate teacher and examiner no less than examinee.* (p.528)

Summary

The diagram below is an attempt to provide an overview of some of the arguments presented in this paper as we, inevitably, must transition from a modern science [education] built on some foundational propositions and perspectives, to a future oriented science [education] which learns from the mistakes of the past and endeavours to put the Earth at the centre of our thinking rather than commercial exploitation.



What does this mean for Science Education Futures? The following are some suggestions that emerge from the visions this paper has endeavoured to present. We should let Nature be the teacher. Ensure its presence as the natural environment in which our mind develops and learning takes place. Thus we should start with experience. The expert is one who experiences. To experience we should use the body in order to move and act. The human body is a learning body that explores, discovers and builds through experience. In all our activity we should use technology wisely. Consider carefully the human value schemes and the socio-economic interests involved in its development. As we learn we should integrate the scientific knowledge we build with other knowledges. Interdisciplinary and transdisciplinary perspectives enhance the why, the what and the how of science. Above all, we should remember the doughnut! Our future (not just that of science) depends on maintaining the fragile balance between environmental safety and social justice.

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