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LINKING TRANSDISCIPLINARITY PRACTICE TO SOUTH AFRICAN SCIENCE, TECHNOLOGY AND INNOVATION POLICY

Reflections on how transdisciplinarity can play a role in assessing the challenges facing South Africa, and in creating the means to think, act and innovate to address these challenges.

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Abstract

We have entered the Anthropocene epoch[i] with its unique challenges caused by transforming geopolitics and the establishment of new areas of interest such as eco-socialism, bio-politics and socio-capitalism. These areas acknowledge that science, in its relationship with technology and the economy, is not able to easily provide single solutions to complex problems. The Anthropogenic realisation that the earth is not a passive recipient (and resource) of humankind's actions, is bringing about realisation of the need for humanity to devise new ways of thinking and doing. This is where transdisciplinarity could play a crucial role as it assists us with the mechanisms to not only grasp the scale of the complexity humanity faces, but also provides us with the means to think, act and create innovatively.

The South African Department of Science and Innovation (DSI), (previously called the Department of Science and Technology – DST), in response to this challenge, released the White Paper on Science, Technology and Innovation in 2019 (DSI, 2019). The core aim of the report is to advance innovation through inclusivity, transformation, and partnerships in order to meet new, complex demands. The content of the DSI 2019 White Paper followed the adoption of the Department of Arts, Culture, Science, Technology, (DACST) White Paper on Science and Technology in 1996. The 2011 adoption of the National Development Plan: vision for 2030 (NPC, 2011), identified Science, Technology and Innovation (STI) as primary drivers of economic growth, job creation and socio-economic reform. The NPC (2011) serves as the government guide to fostering wellbeing, addressing poverty and supporting a robust, entrepreneurial and innovative economy for all people in South Africa. According to the DSI White Paper (2019), science, technology and innovation (STI), while serving as drivers for the country's economy, industry and sustainability, should also embody some of the best qualities of humanity by instilling curiosity, creativity and aspirational thinking. This is a very ambitious ideal.

A solution to the complexity faced comes in the form of primarily embracing *innovation* as key to *progress*; supported by a transdisciplinary approach to the creative process. As stated by the White Paper (1996: 10) of the Department of Arts, Culture, Science and Technology (DACST):*'Traditional ways of producing knowledge within single disciplines and institutions are being supplemented by knowledge generated within various applied contexts. This is knowledge that is collaboratively created within multidisciplinary and transdisciplinary research programmes directed to specific problems identified within social and economic systems'*. The development of new ideas into marketable innovative products has become imperative to *sustainable development.* This process is considered to facilitate the impact of the

4^{th} Industrial Revolution (4IR) on society and to support, at best, the Paris Agreement (United Nations for Climate Change, 2016) and the Green New Deal (Klein, 2019).

This paper will explore the historiographical (origin and shifts in meaning over time) and sociological positioning (networks and organisations) of transdisciplinarity in assessing the supportive role it plays in transforming new creative ideas into marketable products. The content follows on a previous Mapungubwe Institute of Strategic Reflection (MISTRA) study (MISTRA, 2014). That study addressed the transdisciplinary transcendence encountered within the science and society dichotomy, and looked at the transgressive approach to disciplinary specialisation. Through three selected case studies, a transdisciplinary approach to research was explored in context of climate change, human rights and education. The MISTRA (2014) research was positioned within an African context. The literature review covered, somewhat briefly, a lineage that spans ancient African holistic cosmology (Ubuntu) and Africology (Nabudere, 2011,2012), to the influence of modern day science rebels on the intellectual origin and nature of transdisciplinarity (Feyerabend, 1975; Gadamer, 1975).

This paper will expand upon two recommendations of the MISTRA 2014 publication, namely to keep transdisciplinarity central to current socio-political and economic challenges and to address the current fragmentation of knowledge creation. The focus will be on the linkages between transdisciplinarity, innovation, citizen science and grassroots innovation that have become evident in the DSI White Paper (2019). One should take into account that the transdisciplinary approach refers, by nature and through necessity, to 'science' as a collective term of all academic disciplines ranging from the natural sciences, social sciences and humanities. This inclusive reference enables us, within the science and society context (MASIS,2009, 2012), to explore, as an example, the capability of South Africa's science culture and science literacy. The contention is that a robust science culture and science literacy are both required in order to sufficiently support the activities of potential innovators, as indicated in the DSI White Paper's (2019) wish to fulfil its vision for 2030.

Introduction

The transformation of society was regarded, until recently, as being shaped by unified and exclusive scientific and technological progress, driven by the privileged and preference of a Science, Technology, Engineering and Maths (STEM) based education system (Medium Term Strategic Framework (MTSF) 2014-2019). This exclusive take on science was mostly driven by the perception that 'good men do good science', that science is always altruistically motivated and acts on behalf of society. Culture, as represented in the Humanities and Social Science (HSS), functioned as a platform for the socialisation of science or as mere supplementary handmaiden. Even when a new paradigm called 'science and society' emerged from the European Union (EU) MASIS Report (2009, 2012) [ii], most attention remained on the positive aspects of science and, at best, society was considered as a recipient of the benevolence of Science and Technology (S&T). This attitude often constrained the possibilities for meaningful social change - especially within the restrictions of empirical terminology conveniently 'regulated' by bibliometric data (Mayer-Schönberger, 2013).

In current times, anxiety about social, political and ecological sustainability is creating awareness of complexities beyond scientific control, pointing to the need for unity between social actions and interactions on science, and *vice versa*. It is within this context that transdisciplinarity is identified as useful since it brings together actors from the sciences, social sciences and humanities. It is a necessary step to consider since, within this context, it could be recognised that the current 'knowledge society', seen in context of a dystopia, is promoting inequality between the knowledge-rich and the knowledge-poor. Knowledge is increasingly considered as commercially generated data (information) and not based on wisdom (epistemology).

This preference for information above knowledge compromises rational discourse and generates environmental, ethical and intellectual risk (Nowotny et al., 2001). Nowhere is the need for informed knowledge and social adjustments to science findings more pronounced than in the global spread of the coronavirus SARS-CoV-2, named COVID 19, that was first identified during December 2019 in Wuhan, Hubei Province, in China. With this pandemic health threat, humanity has seldom witnessed the transformation of the geopolitical landscape in such a radical manner and seldom has society been subjected to such drastic social curtailing of habits and norms. Within the science and society landscape, the ability to identify a new virus, the logistics of tracing its global spread through data collection and the ability to communicate with societies on global scale is setting humanity on a new path of scientific reality, political capability and social ability. It is a defining time in humanity's history on this planet and has raised awareness of the value of sound scientific knowledge above mere information. Most importantly, this pandemic illustrates the necessity of transdisciplinarity to create meaning beyond disciplinary specialisation.

The South African government is exploring strategies to support the creation of new knowledge in the uncertain environment of Anthropogenic transformations, in, for example, the DSI Science Engagement Strategy (SES, 2015). The aim and proposed actions of SES (2015) underpin the South African government's constitutional obligation to inculcate rational attitudes and values amongst lay people. This is to enable them to participate in public policy making and to contribute, in a rational and informed way, to the social wellbeing of the nation. It is generally accepted that a positive and informed attitude towards science, a knowledge of maths and a fair judiciary is necessary for stabilising our democracy. These concerns are important while South Africa is moving from a traditional, resource-based (extraction) economy to a knowledge-based economy. The traditional take is that a knowledge-based economy requires, *inter alia*, people who are skilled and educated in science and maths. Scientists must be able to conduct research, generate data and undertake developmental initiatives to maintain or increase production of goods and services within an economic framework. This should be done while maintaining a healthy balance with, and understanding of, the environmental issues necessary to mitigate and adapt to, for example, the impact of climate disaster and its risks.

In this broader context the transdisciplinary approach to research, as proposed by the DSI White Paper (2019), must guide an organised and structured process of problem-solving capabilities. When innovation and technical abilities (scientism and technicism) receive priority attention from government, it is often not mentioned that innovation, per se, is not only to be found in tangible products, but also in social research and theorising, historical narration and philosophical reflection. Knowledge is also not only institutionally generated and regulated. In the real world, knowledge is also created in society through transdisciplinary approaches by people who are problem focussed, interact with their environment and aim at practical solutions.

Science research (for example on DNA, viruses and bacteria[iii]) is opening up new frontiers of understanding about where we come from and how we are biologically constituted. Transdisciplinarity provides the means to bring this scientific knowledge into the context of where we come from, who we are, how we need to act and what future we require for survival. Furthermore, the importance of *all* forms of life (not only human life), is recognised in order to understand current forces of eco-socialism, bio-politics, socio-capitalism and ecological disruptions.

To meet the ecological and geopolitical needs of today's world, academia might well consider that it is facing a crisis of outdated concepts, methodologies and dependence on classic philosophies. Since currently we are, after all, embracing '… a radically different order of society based on open access, decentralised creativity, collaborative intelligence, and cheap and easy sharing' (Bollier, 2008:11).

Science Culture

A positive attitude towards science is still evident in the DSI White Paper (2019)[iv]. It is supported by the prominence given to STI indicators, developed in 2015 by the National Advisory Council on Innovation (NACI), as well as SES (2015). Recommendations [v] were made based on the perception that science will 'come to our rescue ' by scientists continuing the work that 'good' scientists do. In addition, the hope is expressed that science will assist the presumed scientifically-informed society to become innovative. This complex perception of the importance of science, in its singular definition of representing the natural sciences, so-called hard sciences and mathematics, remains a debilitating factor. We need the inclusive knowledge support of all disciplines. We need the expanding of knowledge within the science and society paradigm through the development of the science culture of our country. This process should take society, culture and social preferences into account. If we have a robust science culture, the public will be provided with adequate knowledge about science and technology. Such a culture will speak to what is useful to understand, question new findings and put into practice necessary transformations within a social context. Also, a scientific culture will support a shared belief that scientific expertise can be trusted. This will enable the provision of information about what is scientifically plausible and possible, and what is not. Most crucial, a robust science culture could support the innovation potential of a social group - with the potential of economic benefit. Measuring a science culture, something desirable and necessary, will assist in establishing the degree to which our society is socially engaged and supportive of science.

With the global dominance of techno-science, it unfortunately became the primary and broad mode through which individuals and society appropriate, communicate and consider science and technology (Godin and Gingras, 2000). However, the *culture of science* is not restricted to only one mode of engagement but happens on a continuous scale between all disciplines. Fernand Braudel's (2009) concept of *longue durée* captures this historical line which extends beyond academic disciplines, human memory and even archaeological records and is found in climatology, demography, geology, and oceanology. A more current (if somewhat limiting) understanding of science culture is primarily traceable by the ways in which scholars, scientists and policy-makers support and discuss science and society issues (Council of Canadian Academies, 2014). The foundation of a science culture, however, depends on *social aspects* and is supported by the *social sciences and humanities*.

A number of similar terminologies to *science culture* are referred to, such as scientific literacy and scientific culture (Miller, 1983; Shen, 1975). Scientific literacy is considered to be an individual's ability to have a basic understanding of scientific concepts and processes required for personal decision-making. This capacity will enable the individual to participate in social and cultural affairs and, in this case, support the innovation process. It is an indication of a person's level of understanding of science and technology. It is a necessity to be able to function as a citizen in a modern industrial society. It is also a requirement for strengthening democracy, as it promotes a rational and informed society. A scientifically literate person will have the ability to read, with understanding, articles about science in the popular press and engage in conversations about the validity of scientific inventions. A scientifically literate person will develop an understanding of scientific methods and an appreciation of the quality of scientific information shared by the media and science communicators (Miller, 1998; Shumba, 1999; Durant, 1994). These qualities, most importantly, will equip a person to become innovative.

Science literacy is broadly conceptualised within two dimensions. These are practical scientific literacy, which indicates scientific knowledge that can be applied to help solve practical problems, and civic scientific literacy, which enables a citizen to become more aware of science and science-related issues and thus participate more fully in the democratic socio-political processes of an increasingly technological society (Shen, 1975; Miller, 1998, 1983; Shumba, 1999; Durant, 1994). These terms differ and Martin Bauer (2012), for example, proposed that a language convention might be useful to distinguish between the cultural application of terms like 'scientific culture' and 'science culture', taking as lead reference the definition by Sorokin (1985: 2):

> '… everything which is created or modified by the conscious or unconscious activity of two or more individuals interacting with each other or conditioning each other's behaviour…. science, philosophy, religion, art, technics and all the physical paraphernalia of advanced civilisations, are cultural phenomena'.

Supporting a robust science culture will have advantages. Most crucially, a creative and scientifically literate person will have the ability to transform scientific information into innovative products. John Miller (1983) previously emphasised that in a democratic society, the level of scientific literacy in the population has important implications for science policy decisions and assists in improving the quality of science, technology and political life. Globally, countries are currently inundated with issues relating to a sophisticated public outreach, and with science engagement processes required to overcome the perceptual gridlock, caused by false information, on climate change and serious health matters. This includes issues like encouraging public acceptance of the teaching of evolution in schools and meaningfully involving the public in decisions about topics such as biotechnological legislation and nanotechnology regulation. Policy development and policy application occurs through public participation (Scheufele, 2014). Information provides a supportive context for innovation as well as inspiration to develop projects and change operational systems.

In South Africa, the tension between taking into consideration the public's traditional knowledge systems (IKS) and the often-conflicting nature of such systems with practices based on scientific findings, are ever present (Hountondji, 2002; Ramose, 2002). We may speak of the necessity to move beyond the current conceptual opposition between empirical knowledge (including IKS) and rationalist (mostly science) knowledge. This involves moving beyond ideological imperatives; it also entails acknowledgement of such divisions being co-implicative and in need of a certain amount of radicalisation (du Plessis, 2010). In this context we further require a transdisciplinary look at epistemic justice and hermeneutic credibility (Fricker, 2013). With science often directing the normative behaviour of a society, Habermas (1966) introduced us to a 'decisionistic' model that proposes a critical interrelation between science and politics, rather than a strict division of functions. In addition, communication and policy support underpin the possibility of a successful social contract between state and society (McCandles, 2018).

Interlinked Global challenges

Within the context of recognising a difference between scientific knowledge *per se* and scientific expertise, we consider science relevant in its relation to decision-making processes, and its provision of knowledge within an expert-client relationship (Hans-Peters, 2008). To paint a broad picture of the main issues global societies are facing, we should take note of the following: there is growing proof and social awareness that the current planetary ecological instability is leading to global-scale social unrest and uncertainty. These economic and political uncertainties we face are the cause of the current 'age of anxiety or then 'age of anger', and are often driven by fear (Mishra, 2017). Scenarios creating anxiety arise from scientific, evidence -based research, in which scientists are warning us that the planet is entering an unstable ecological stage (Pearce, 2006; 2007). Ecological and climate instability on a planetary scale is caused by the ascent of the Anthropocene (Smith, 2018). The uncertainty of this ecological future is causing anger against political as well as economic failures (Mishra, 2017; Fukuyama, 2014). In addition, our neo-liberal economic system is blamed for creating global social inequality and poverty (Banerjee and Duflo, 2011). Despite science and technology promising a better life for all, we face regulatory technology-based restrictions that cause emotional misery (Monbiot ,2017; Lanier, 2014); we witness labour dislocated from the marketplace (Rifkin, 2000) and face disruptive social networks (Castells, 2012).

It is becoming difficult to imagine a future within the current economic system (neo-liberal, globalisation) with its perception of universal, continuous, undifferentiated and unimpeded growth (Stiglitz, 2002; Mason, 2015). It is even more difficult to imagine a future within an ecological system that is transforming radically and often violently (Pearce, 2006, 2007; Barnosky et al., 2015; Lovelock, 2009, 2014; Weisman, 2013). It is currently said that humankind is 'living in the end' times (Žižek, 2010, 2016), creating a 'culture of fear' caused by tracing the historical decline of civilisations (Jacques, 2012; Rancière, 2011; Diamond, 2005; Acemoglu and Robinson, 2012; Bongiovanni, 2012). We also have what Francesco Bongiovanni (2012: 6) refers to as the 'Civilisation of Entitlements' – based on an unsustainable foundation of multi-dimensional economic and socio-political actions that brought peace to the European region at the cost of other countries' stability. These reasons for anxiety are to be found in the demographic, geographic and environmental consequences of our current regulatory systems (governance) and life choices which science informs us are increasingly considered to be ecologically destructive, socially unfair and economically unsustainable. Solutions and innovations are seldom found in the often-narrow constraints of academic-based disciplinary specialisation, though it can be good at identifying problems.

It has been argued by Helga Nowotny (2006) and others (Bhaskar, 1975; Feyrabend, 1975; Gibbons, 1994; Stiegler, 2018; Žižek, 2010, 2016) that we need to break this cycle of fear which is the inevitable result of planetary as well as social instability. The socio-technical systems we invented are growing in complexity to such an extent that, instead of promising a stable work future, these systems are facilitating dissent while undermining the modern (traditional) employment environment. Hence the repeated reference to the 'new working class', the *precariat*, that is on the rise (Standing, 2010). It is amongst this group that we encounter what is possibly the biggest social challenge of the future. A challenge that is witnessing emerging identities based on anger, anomie, anxiety and alienation amongst those from groups such as the atavistic-populists (characterised by support for neo-fascist parties and populist demagogues); the anarchic detached (display anomic, anti-social behaviour) and the idealistic-progressives (or utopian-progressives) (Standing, 2010, 2012, 2017). We could even identify the emergence of two global anti-systemic movements: the 'social movements' (addressing oppression by employers) and the 'national movements' (addressing oppression of ethno-national groups) (Arrighi et al., 1989).

Where modern systems thrived on hierarchical and centralised control structures, the new technologies are facilitating a much more horizontally-networked control that mostly thrives on heterogeneity (Ferguson, 2017). As a result, institutional control of the creation of new knowledge is becoming difficult to manage and regulate. South Africa's institutional and disciplinary control processes risk being marginalised with the participation in the creation of new knowledge through citizen science and online platforms like the Science Commons and Open Science. This is particularly noticeable in the rise in globally-linked social movements and social uprisings based on socio-political and economic dissent (Campagna, 2012).

Innovation for the people by the people – the DTI White Paper (2019)

It is against this background that we need to consider the logic of promoting a transdisciplinary approach to support innovation. The 2011 National Development Plan (NDP) and the National System of Innovation (NSI) highlighted the centrality of science, technology and innovation (STI) in national development[vi]. The NPC (2011) notes that development in STI could fundamentally alter the way people live, communicate and transact, with profound effects on economic growth and development. The NPC (2011) further indicates that countries that are able to tackle poverty effectively by growing their economies are characterised by strong STI. This implies that STI is fundamental for the promotion of equitable economic growth which underpins economic advances and improvements in health systems, education and infrastructure. Furthermore, the NPC (2011) acknowledges that STI and the NSI have roles to play in improving South Africa's global competitiveness. This is significant since the trend to support innovation is a globally popular aim as we witness in Europe, China and Russia.

Two new bold steps are included in the DSI White Paper (2019):

1.The inclusion of innovation as an imperative to social and economic growth.

2. The proposed transdisciplinary approach to problem-solving to be applied as mechanism to ensure growth and development of research and to enable and facilitate innovation process[vii].

Transdisciplinarity in context

The failure of humankind to live in harmony with nature, within a mostly consumer-based culture, is causing the end of eco-stability within a geographical context. This creates opportunity for change, for innovation and for re-thinking ways in which we create knowledge. This opportunity inspired Basarab Nicolescu and others (Nicolescu, 2002; Gibbons, 1994; Nowotny, 2006, 2003; Cilliers, 1998) with the idea that, in order to overcome the demise of our eco-stability we need to move beyond the restrictive sphere of disciplinary-bound research processes to create new useful knowledge. A transdisciplinary approach to research was proposed that will enable us to not only escape restrictive disciplinary approaches to research, but will assist us to engage simultaneously with different levels of reality, consisting of three different axioms: the ontological, the logical and the complex (Nicolescu, 2002).

A theoretical understanding of the transdisciplinary approach has developed in tandem with a better understanding of transdisciplinarity in practice (Lang et al., 2012), and of the complexity of the approach in relation to various systems (Cilliers, 1998). This theoretical consensus contends that a transdisciplinary approach is useful to transgress and transcend the growing disciplinary compartmentalisation and specialisation that is characteristic of our times. This is because transdisciplinarity promotes mutual learning between science and practice, and provides access to socially robust knowledge. It also, provides space for resolution of the problems that arise between science, democracy and the market economy and, most importantly, tears down the barriers between the sciences (Klein et al., 2001). A practical approach to transdisciplinarity supports the resilient dynamics required to face current complex socio-ecological systems in our quest social stability (Folke, 2006). It integrates a number of academic disciplines, their multiple knowledges and knowledge embedded in society (IKS) by looking at an identified (wicked) problem in order to bring about transformation.

It is in this context that transdisciplinarity plays a crucial role in the innovation process.

The inclusion of a transdisciplinary approach to research in the DSI White Paper (2019) therefore provides a timeous and appropriate acknowledgement of the usefulness of transdisciplinarity. With the growing emphasis on the scientific as well as social value of innovation, this inclusion is to be welcomed. Innovation, linked to transdisciplinarity, is recognized globally and is already acquiring certain characteristics - such as the reference to the collective imperatives of science, democracy, humanities and the economy. Transdisciplinarity promotes an integration of approaches in order to focus on solving joint problems within the science-technology-society triad.

What is Transdisciplinarity?

The concept of transdisciplinarity has a historical context that aligns strategically with the disciplinary specialisation characteristics of academia. Transdisciplinarity is closely linked to the way in which knowledge (epistemology) is being created, within its own transgressions and modes of creation – conveniently referred to as Mode 1 (deficit model) and Mode 2 (impact orientated) knowledge production[viii]. Though explanations regarding the shift from Mode 1 to Mode 2 of knowledge production provide a glimpse of new possibilities for resolving global problems, there is still only a slow uptake of a transdisciplinary approach to research, and this approach is challenging to apply. (For note: transdisciplinarity is not community outreach and it is not to be seen as a 'methodology': it is an approach.)

Often restrictively, disciplinary specialisation reinforces knowledge already known by applying, through conventional methodologies, normative notions of behaviour. We already acknowledge that academia is ruled by the repeated reference to a 'unity of disciplinary action' - action that requires the sciences to be directed towards a purpose-filled strategic direction. Academics are persistently and repeatedly required to indicate an accepted discipline bound 'course of action' (scientific method) to achieve discipline-specific and often predictable results. However, in recent times discipline-embedded theories and methods are increasingly being challenged due to their conformity, blind acceptance of ruling paradigms, often undeserved reverence for academia and political authority, and their stifling specialisation and prescriptive methodologies.

This then leads us to the requirement to better understand the growing importance of a transdisciplinarity approach to research, in recognition of the value of exploring a selected topic (wicked problem) in a united and boundless intellectual manner, creating opportunity for new knowledge.

In short, transdisciplinarity is an enquiry-based approach to research (rather than discipline based) and is used to connect discipline-specific content with contextualized knowledge (Volckman, 2009). This opens up a multitude of new possibilities and enables us to combine empathy, care, values, ethics, inclusivity, and social justice with science. It also provides new scope for a renewed appreciation of hermeneutics (which refers to the inherent circularity of all understanding, where comprehension can only be achieved through tacit foreknowledge) and the linking of theory with practice (praxis) (Caputo, 2018). Hans-George

Gadamer (1975) already proposed that knowledge begins with practical knowledge that informs a particular hermeneutical situation, so in our current circumstances we are now able to identify, for example, the role played by prejudice and the authority of tradition in the production of knowledge and understanding.

Transdisciplinarity refers to the reconfiguring and re-contextualisation of existing and available knowledge into knowledge that is socially robust, accountable, and reflexive (McGregor, 2015). This speaks strongly to the ambition of establishing a strong science culture in society. In turn, a strong science culture underpins innovation. Julie Klein (2014, 2001) in this context refers to the possibility of transdisciplinarity facilitating aspects of transcendence and transgression in the research and innovation process.

From another angle we may argue that transdisciplinarity is central to societies seeking to address the debilitating socio-pathology of oppression of the mind, including the negative forces of colonialisation and globalisation, especially in post-1994 South Africa. Here transdisciplinarity is important, where past colonial inheritances have to be remodelled to fit with the pressures of the present and its demands. Therefore, the politics of knowledge production has a bearing on strategies devised to rebuild a society disrupted by structural inequality and political disempowerment. Knowledge production histories and institutions have to be interrogated to adjust their parameters for change and transformation frameworks; this is because the global evolution of knowledge influences the paradigms of local knowledge the local knowledge paradigmatic dimensions (MISTRA, 2014).

We may claim that a transdisciplinary approach is essential in the innovation process. Transdisciplinarity is well positioned to facilitate mutual learning between disciplines and the accessing of socially robust knowledge. It is clear that the complexity of problems faced by global societies requires an understanding of complex systems and here transdisciplinarity plays a *conciliatory* role (Cilliers,1998).

The aims of transdisciplinarity intersect with the intentions to share new knowledge, include IKS and consult with communities to solve problems collaboratively. Participation of non-scientists in policy issues that have technical or scientific components should be based on the active engagement with scientists (Bell et al., 2009; Mayer-Schönberger, 2013).

Relation of transdisciplinarity to innovation

Through linking technology with knowledge creation, the first theories appeared about a new way of knowledge production that appealed to politicians and civil servants who were struggling to link science with innovation (Gibbons, 1994; Nowotny, 2006, 2003). Aided by science, and driven by human ingenuity and curiosity, the development of technology initially formed the core of innovation processes. However, these innovation processes, according to Helga Nowotny (2006: 4), soon became '… an endogenous phenomenon, embedded in a conventional (orthodox) neoclassical economic theory; therefore, innovation became trapped in economic thought'. *Thinking differently* might resolve the conceptual void that developed, with innovation considered as an economic and technological process that could act as steward to communal bio-physical resource. For transdisciplinarity to be of special social value requires the pro-activeness of innovation and entrepreneurship. Such pro-active action is only possible when creativeness is supported by a transdisciplinary approach, beyond the constraints of a restrictive deficit mode (linear model) of thinking (Mode 1). We can therefore safely propose that, with growing evidence that the continued specialisation of separate disciplines is not conducive to solving the so-called 'wicked' and complex problems the world is currently facing, we need to adopt creative and new approaches that facilitate all-inclusive innovation.

The relation between transdisciplinarity and innovation is strong and is possibly the most important strategic research shift in recent times. With research initiatives being steered towards a transdisciplinary approach by international bodies such as the European Community Framework (ECF) and the European Climate Foundation (ECF), a call for science to be ecologically and socially accountable highlights acknowledgement of the complexity and the reflexive use of transdisciplinarity in the quest for innovation (Klein, 2014). There is growing evidence that science (in its all-inclusive sense) did not bring with it improvement in humanity's moral standards and social behaviour. We encounter the strange dichotomy that science, in alliance with technology, developed hugely destructive devices such as the nuclear bomb. As Helga Nowotny (2006: 8) stated: '… scientific and technical progress has not prevented society from falling back into a state of incredibly cruel destruction and barbarity…'. However the same nuclear technology is enabling the medical sciences to save millions of lives. Despite the progress we have made due to technology, we also now have to deal with negative impact of our collective actions through the acknowledgement of an epochal shift to the Anthropocene. We need to reflect on unrelenting technological advances and humanity's destructiveness, based on an extraction economy, while dreaming of progress (Crutzen, 2002).

Reflections on the broad scope of themes and theories based on a transdisciplinary approach:

1. De-institutionalised hyper-specialisations

We live in times of hyper specialisation where humanity, as Elijah Millgram (2015) argued, created a modern-day Tower of Babel in which the epistemic autonomy required for responsible democratic citizenship might well be an illusion. We find new specialities emerging in an effort to capture the complexity of what we now realise we face in the future, creating even more specialisations. Some examples include: the Agnotocene, which studies the production of ‘zones of ignorance’ (Bonneuil et al., 2016), the use of the word Anglocene (within context of world domination by Britain and USA) and the Anthroboscene which will require us to move beyond material realities presented by the media, by re-visiting the earth’s history, geological formations, minerals, and energy (Parrika, 2015). The Chuthulucene (Haraway, 2016) explores more-than-human alliances within diverse earth-wide powers and forces, in which refugees from environmental disasters (both human and non-human) will come together. This predicts the dystopian time when humans will try to live in balance and harmony with nature (or what’s left of it) in ‘mixed assemblages’ . The Homogenocene, with its take on diminishing biodiversity and biogeography, argues that ecosystems around the globe will seem more and more similar to one another mainly due to invasive species (Mann, 2012). Finally, James Lovelock’s Novacene (Lovelock, 2019) argues that future humanity will be defined by novelty and artificial hybridisation. How do we adequately respond to the nearly obscene exponential thinking and theorising around the Anthropocene within this vast plurality of what is popularly referred to as a *'cene-salad'*?[ix]

New thinking is also escaping the singularity of academic disciplines. New fields of research develop outside of disciplinary boundaries, posing new theoretical frameworks and ways of thinking such as eco-socialism, bio-politics and bio-power; represented and accommodated through social networks. Areas such as post-humanism, rejecting claims founded on ethnocentric dominance, counter hyper specialisation and instead address questions of ethics and justice. Epistemic justice, in this context, must consists of both testimonial injustice and hermeneutical injustice (Fricker, 2009, 2013). Research on the role of language and trans-species communication within social systems is growing in importance. The trans-humanists are focussing on the modification of the human species via genetic engineering, digital technology, and bio-engineering (cryogenic life extension and cyborgs) and is sometimes known as futurism or extropianism. We also encounter the anti-humanist view which rejects the notion that humanity is the ‘evangelic’ overseer of all life on earth, since scientific evidence shows that the homo sapiens species is carrying out a predatory, ferocious assault against all non-human life. In relation to humanity’s alienation from nature, we witness what Masao Miyoshi (2010) described as the reproduction of bureaucracy with the sole aim of expanding itself and converting scholars into corporate employees and managers. This task is made easy with the technology-society that is facilitating the spread of de-socialised individualism, self-interest and self-indulgence. We witness preferences for information (social media gossip and announcements) instead of deep knowledge based on historically contextualised reflections on new scientific findings.

2. Citizen Science

Citizen science is a rapidly expanding research field involving alternative and supportive models of public knowledge suitable for the co-creation of academic knowledge. A transdisciplinary approach fits well with this kind of co-creation of knowledge, and strengthens innovation through a variety of knowledge domains, perspectives and information platforms. Through citizen science we create organised short-term data collection through fieldwork, facilitate the voluntary sharing of local knowledge(s) and expand community participation with scientific research projects (Bonney et al., 2014; Bonney et al., 2009). Citizen science enables the strengthening of existing structures and frameworks within the scientific process, enables the building of new infrastructures and, most significantly, integrates these structures and scientific procedures into society, science, technology, media, education and policy (Hecker, 2018).The claim that transdisciplinarity enables us to approach knowledge on various levels of reality also implies that we use different types of intelligence (analytical intelligence and emotional intelligence) to create new knowledge. Therefore, when transdisciplinary unites Citizen science and science actors around the exploration of a common theme, it often involves collaboration between academics and non-academic groups such as citizens, artists and indigenous people. From another perspective we could also propose that citizens, artists and indigenous people can access academic (re)sources to complement, enhance and inform the knowledge they apply in innovation outside of the academic domain.

Citizen science is an old practice[x]. Astronomy, as example, has long been a field where amateurs have contributed to science (Jeppie et al., 2008). Counting species or reporting sightings of birds, butterflies and mammals and even selectively collecting debris on the coast are all popular Citizen science topics. Cooper (2018) demonstrates Citizen science contributions in the fields of Meteorology, Ornithology, Entomology, Biochemistry, Microbiology, Geography and Conservation and Marine Biology. Citizen science may be performed by individuals, teams, or networks of volunteers. Citizen science takes place in the form of crowd actions, volunteer monitoring, or networked science topics. Citizen science may be described as public participation in scientific research, since it requires participatory monitoring, and participatory action research (Cooper, 2018).

Recognition for the beneficial role that Citizen science plays in the creation of knowledge is fairly recent. A 'Green Paper on Citizen Science' was published in 2013 by the European Commission's Digital Science Unit and Society, which included the definition:

> Citizen Science refers to the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources. Participants provide experimental data and facilities for researchers, raise new questions and co-create a new scientific culture [xi].

The DSI White Paper (2019) aptly recognizes the importance of Citizen science and specifically the importance it plays in activities related to grassroots innovation. The focus remains on technology and its benefits (DSI White Paper 2019: 4, 10, 53):

> Civil society will also be assisted in its many roles, including as a source of innovation, information, mentorship and networks. Efforts will be made to strategically link this sector to NSI actors such as technology stations and science councils. Its function as innovation intermediary between government and grassroots innovators will be strengthened. Training packages will be developed, using social media and digital technologies, to equip civil society with innovation development skills. Collaboration within the civil society sector will be strengthened and incentivised, including partnerships with publicly funded R&D institutions and science councils in piloting and distributing technology for public benefit'

Today Citizen science use new technologies that are increasing the options for local observations. Citizen scientists can build and operate their own instruments to gather data for their experiments. Examples include amateur radio and amateur astronomy. Open Source hardware (scientific equipment), Open Data Open Science and the Science Commons are networks used by Citizen scientists (Bollier, 2008; Boyd, 2012). The danger persists that the DSI (2019) might continue preferring and privileging science and technology and neglect the importance of the humanities and social sciences. It is in this context that transdisciplinarity is a useful approach which might assist in breaking this deadlock.

3. Grassroots innovation

To bring about the much-needed change from innovation to investment, the Department of Science and Technology (DST), in collaboration with its entity, the Technology Innovation Agency (TIA), officially launched the Grassroots Innovation Programme (GIP) in March 2019. GIP is designed to identify and support innovators and inventors who do not have a formal education or access to formal innovation facilities.

Grassroots innovation speaks to the way people live with a practical understanding of the ecological integrity of their environment. People undertake actions to create a habitable space according to need. Their actions are probably the best example of a transdisciplinary approach to the environment through adapting to a changing climate and its ecological fall-out. One example is evident in the changes in agricultural practices: crops are planted much later in the season due to climate change. The penetration of the media, technology, industry, modern economics and scientifically-generated new knowledge brought about transformations through the introduction of new systems (planting cycles) and products. Some transformations, such as crop monocultures in agriculture, now ignore previous preconditions of biodiversity and require farming adaptations. It is a case of humanity having to adjust to a transformed nature (Anthropocene) and the socio-political dominance brought about by technology (Shrivastava & Kothari, 2012).

The original aim of grassroots innovation is to establish a sustainable livelihood. There are three challenges facing transdisciplinary teams embarking upon the grassroots innovation process. The first is the ability to attend to local specificities whilst simultaneously seeking wide-scale diffusion. The second is the need to identify suitable existing situations that one can seek to transform. The third challenge is to find ways to work with project-based solutions to achieve goals of social justice where the root causes of injustice rest in structures of economic and political power. Each challenge effectively frames grassroots innovation differently, and responses generate valuable forms of knowledge production: grassroots ingenuity; grassroots empowerment; and structural critique (Smith et al., 2014; Bell et al., 2009).

Concluding examples

Against the background that was provided about Anthropogenic planetary changes and its threat to the ecology, a transdisciplinary approach to solving problems and bringing about innovation, was recognised as a possibility in South African Governmental planning. Innovation, and the foundations for a science culture, are considered as driver for change and come with a transdisciplinary approach as proposed action.

Different countries recognize the current eco-economic challenges we face, and though they react differently to them, they apply transdisciplinarity within the domain of innovation.

China identified the necessity of developing a science culture with a scientifically literate population to ensure progress and bring about innovation (Siew et al., 2016). In 1995, the Chinese government convened a major National Conference on Science and Technology and, under the slogan, 'Revitalize the Country through Science and Education', elevated scientific and technological development to a major national policy priority. With innovation high on government agenda, President Hu Jintao announced a commitment to make 21st century China an 'innovation-oriented society'. This announcement was made at an important China National Science and Technology Conference in January 2006. The occasion also saw the unveiling of a new 15 year Medium to Long-term Plan for the Development of Science and Technology (2006-2020)[xii].The China Academy of Science (CAS) is currently introducing a 'culture of innovation' that is taking a variety of forms, from new attention to the ethics of research, to a new commitment to popularisation and science-society relations. We find scientists responsible for transdisciplinary knowledge integration as important members of research teams. These transdisciplinary specialists have knowledge of other scientists, disciplinary specialties and local stakeholders to ensure cross–sectorial knowledge integration (Siew et al., 2016).

Further international examples exist of monitoring and evaluation systems being applied to measure the inclusion of an innovation imperative. In many regards these actions take place under the auspices of the need to communicate science. As a global example, France and Switzerland are quite active in promoting transdisciplinarity. In Paris, France the International Centre for Transdisciplinary Research (CIRET) was founded in 1987 with Basarab Nicolescu as President. In 2000, the network td-net was launched by the Swiss Academic Society for Environmental Research and Ecology (SAGUF), later taken over by the Swiss Academy of Sciences (SCNAT) in 2003. Since 2008, the td-net network for transdisciplinary research is a project of the Swiss Academies of Arts and Sciences. The practical aspect of transdisciplinarity has been well documented in Europe (Klein et al., 2001; Hirsch et al., 2008).

The Ministry of Science and Higher Education of the Russian Federation invested in research and development through funding and the appointment of researchers. Russia developed specific innovation indicators and innovation expenditure to track progress in the broad areas of industry, enterprises, services, agriculture and construction. The Centre for Statistics and Monitoring of S&T and Innovation at the Higher School of Economics National Research University in Moscow conducts regular surveys to assess the influence of science and technology on daily life and to measure the public awareness of scientific and technical achievements. This provides data to guide and identify innovation areas in need of support (Magala, 2019).

Innovation is being introduced through the Russian School of Transdisciplinarity (1990). Since its inauguration, several activities took place such as the 1997 formulation of the basic principles of transdisciplinary 'construction of harmonic education'. In 1998 the basic methods were built on specific principles, and these basic methods proved their effectiveness by keeping students healthy and interested in new knowledge. As an autonomous non-commercial organisation, the Institute of Transdisciplinary Technologies opened in 2007 in order to generalise and retain the transdisciplinary experience gained through long-term transdisciplinary research. This Institute took on the task of developing transdisciplinarity as an independent science. It also looks at the development and introduction of solutions to complicated multifactorial problems within a transdisciplinary approach. Through these incentives Russia justified their development of transdisciplinarity.[xiii]

There is evidence that the application of a transdisciplinary approach to research is slowly being established globally. South Africa is joining this trend with the DSI White Paper's (2019) mention and support of a transdisciplinary approach to research. South Africa is reaching out towards a different and excitingly new means to not only look at our national needs, but also to provide us with the opportunity and the means to work globally in resolving global social and eco-economic challenges.

Examples of a transdisciplinary approach to research in South Africa are still few and far between. Though the National Research Foundation (NRF) supports transdisciplinarity, the only dedicated Centre for Transdisciplinary Studies can be found at the University of Fort Hare. The Africa Earth Observatory Network (AEON) and Earth Stewardship Science Research Institute (ESSRI) at Nelson Mandela University produce innovative transdisciplinary data in an effort to 'crack' the shale-gas (fracking) debate: In a study on the reach of transdisciplinarity in research projects, Taufeeq Dhansa et al. (2015) from AEON found that:

> … we are at the threshold of new transdisciplinary thinking about human and natural system complexity, and there is a long list of relevant questions that we must ask, and the relatively poor

growth in transdisciplinarity over the last 5 years remains the most serious challenge to achieving Global Change Grand Challenge goals in South Africa.

The open access *Journal for Transdisciplinary Research in South Africa* was established in 2005 at North West University's Vaal Triangle Campus in Vanderbijlpark. It remains the only local journal of its kind. The Global Change Institute at WITS University embraces a transdisciplinary approach and so does the Future Africa Institute: forging transdisciplinary solutions to Africa's challenges at the University of Pretoria. The Centre for Complex Systems in Transition (CST) at the University of Stellenbosch has already produced valuable work in this domain since 2016 (Van Breda, 2018).

The Mapungubwe Institute for Strategic Reflection (MISTRA) published a book dedicated to the topic of transdisciplinarity (MISTRA, 2014) and transdisciplinarity infuses much of its research outputs. With these humble beginnings one can hope that the logic of a transdisciplinary approach in topics ranging from agriculture and land use, urban and rural development, global climate change adaptation, ecology, e-waste challenges and health will grow in popularity.

As proposed by Robert Frodeman (2013) institutional regulatory practices by academics have seriously misaligned our knowledge production practices;. This implies that the ecology of our knowledge production system is all wrong and fundamentally unsustainable in its practice of ever narrower specialisations, ever narrowing dissertations, and progressively more insular research projects. Not all hyper-specialisations are worth keeping and some are evolving into new clusters of research. An aggressive pruning of disciplines might be needed within academia as well as the embracement of areas that could be adopted and are conducive to a transdisciplinary approach ,such as innovation, grassroots innovation and citizen science.

Recommendations:

From the MISTRA project (MISTRA, 2014) the following conclusions were drawn:

• Transdisciplinarity is central to societies seeking to address the debilitating socio-pathology of oppression of the mind and the negative forces of globalisation.

• Transdisciplinarity is important in an inchoate society such as South Africa where its past inheritance has to be remodelled to fit with the pressures of the present and its demands.

• The politics of knowledge production in South Africa have a bearing on strategies devised to rebuild a society fissured by structural inequality and disempowerment.

• Knowledge production histories and institutes have to be interrogated to situate their parameters for change and transformation frameworks.

• Global evolution of knowledge plays a part in influencing the dimensions of local knowledge paradigms.

• Transdisciplinarity affords a forum for the practicalisation of the imperatives of the Constitution (MISTRA, 2014: 25). Further recommendations are now proposed:

- It is necessary to find support to develop the theoretical framework of a transdisciplinary approach to research through dedicated publications and research papers.
- A NRF-supported South African Research Chairs Initiative (SARChI) Chair in Transdisciplinarity should be instituted to assist in developing a theoretical framework, suitable to South African conditions and requirements, for transdisciplinarity,
- Due to the variety of innovation (re)sources (technology-based, nature-based and culture-based), innovation requires policy built on an understanding of the social complexities of its relation to science and technology. A national survey to establish the science culture prevalent in South Africa will assist in establishing where the indigenous interest areas, based on scientific literacy, are present. This will provide a map of areas high in transdisciplinary adoption and application and in the occurrence of Citizen science activities. It will also highlight where grassroots innovations are strongly occurring. These factors will in turn make it easier to generate support from government to provide for innovation activities. The data generated will be comparable with that provided by international efforts to promote a transdisciplinary approach to innovation.
- It is important to expand the Research and Development (R&D) programme from the 2018 figure of 0.68 per cent, and to support more partnerships between government entities and the private sector to address the R&D funding shortfall.

Roy Bhaskar (1975: 16) took care to emphasise the idea that '…knowledge is a social product, produced by means of antecedent social products; but that the objects of which, in the social activity of science knowledge comes to be produced, exist and act quite independently of men'.

References

Acemoglu, D. & Robinson, J. 2012. *Why Nations Fail: The Origins of Power, Prosperity and Poverty.* New York: Crown Business Publishers.

Arrighi, G., Hopkins, T. & Wallerstein, I. 1989. *Anti-systemic movements*. London: Verso.

Banerjee, A. & Duflo, E. 2011. *Poor economics.* London: Penguin.

Barnosky, A. & Hadly, E. 2015. *End game: tipping point for the planet earth?* London: William Collins Books.

Bauer, M. 2012. 'Science culture and its indicators', in Schiele, B., Claessens, M. & Shunke, S. (eds.). 2012. *Science communication in the world: practices, theories and trends.* Dordtrecht: Springer, pp. 295 – 312.

Bauman, Z. 1998. *Work, consumerism and the new poor.* Buckingham: Open University Press.

Bell, P., Lewenstein, B., Shouse, A. & Feder, M. (eds.). 2009. *Learning science in informal environments: people, places and pursuits.* Washington: National Academies Press.

Bhaskar, R. 1975. *A realist theory of Science*. London: Verso.

Bollier, D. 2008. *Viral spiral: how the commoners built a digital republic of their own*. New York: The New Press.

Bongiovanni, F. 2012. *The decline & fall of Europe*. New York: Palgrave Macmillan.

Bonneuil, C. & Fressoz, J-B. (eds.). 2016. *The Shock of the Anthropocene*. London: Verso.

Bonney, R. Shirk, J. Phillips, T. Cooper, C. Dickenson, J. Kelling, S. & Rosenberg, K. 2009. 'Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy'. *BioScience*, 59, 977-984.

Bonney, R. Shirk, J. Phillips, T. Wiggins, A. Ballard, H. Miller-Rushing, A. & Parrish, J. 2014. 'Next steps for Citizen Science'. *Science*, 343, 1436-1437.

Boyd, D. & Crawford, K. 2012. 'Critical questions for Big Data: Provocations for a cultural, technological, and scholarly phenomenon'. *Information, Communication & Society*, 15 (5), 662–679.

Braudel, F. and Wallerstein, I. 2009. 'History and the Social Sciences: The Longue Durée'. *Review (Fernand Braudel Center)*, 32 (2), 171-203.

Campagna, F. & Campiglio, E. (eds.). 2012. *What are we fighting for: a radical collective manifesto.* London: Pluto Press.

Caputo, J. 2018. *Hermeneutics: facts and interpretation in the Age of Information*. London: Pelican Books.

Castells, M. 2012. *Networks of outrage and hope: social movements in the internet age.* Cambridge: Polity.

Cilliers, P. 1998. *Complexity & Postmodernism: understanding complex systems*. London: Routledge.

Cooper, C. 2018*. Citizen science: how ordinary people are changing the face of discovery*. New York: The Overlook Press.

Council of Canadian Academies. 2014. *Science culture: where Canada stands*. Ottowa (ON): The expert panel on the State of Canada's Science Culture, Council of Canadian Academies.

Crutzen, P. 2002. 'Geology of mankind'. *Nature*, 415(6867), 23, https://doi.org/10.1038/415023a (accessed on 13 November 2019).

White Paper on Science and Technology. 1996. 'Preparing for the 21st century. Department of Arts, Culture, Science and Technology (DACST)', 4 September 1996. https://www.gov.za/sites/default/files/gcis_document/201409/sciencetechnologywhitepaper.pdf, accessed 13 March 2020.

Dhansay, T., Serper, A., Linol, B. Ndlovu, S. Perumal & L. de Wit, M. 2015. 'Transdisciplinarity within South Africa's global change research: How (well?) are we doing?' *South African Journal of Science*, 111 (5/6), 1-4.

Diamond, J. 2005. *Collapse: how societies choose to fail or survive*. London: Penguin.

Du Plessis, H. 2010. The role of women in design, indigenous knowledge systems and science during technology transfer processes. UNISA. PhD thesis.

Durant, J. 1994. 'What is scientific Literacy?'. *European Review*, 2, (1), 83-89 (accessed 28 October 2019).

Ferguson, N. 2017. *The square and the tower: networks, hierarchies and the struggle for global power.* London: Allen Lane.

Feyerabend, P. 1975. *Against Method: Outline of an anarchistic theory of knowledge*. London: NLB.

Folke, C. 2006. 'Resilience: The emergence of a perspective for social–ecological systems analyses'. *Global Environmental Change*, 16 (3), 253-267.

Fricker, M. 2009. *Epistemic injustice: power and the ethics of knowing*. Oxford: Oxford University Press.

Fricker, M. 2013. 'Epistemic justice as a condition of political freedom?' *Synthese*, 190 (7), 1317-332.

Frodeman, R. & Briggle, A. 2016. *Socrates Tenured: The Institutions of 21st-Century Philosophy.* London: Rowman and Littlefield.

Frodeman, R. 2013. *Sustainable Knowledge: A Theory of Interdisciplinarity*. New York: Palgrave Macmillan.

Fukuyama, F. 2014. *Political order and political decay: from the industrial revolution to the globalization of democracy*. London: Profile Books.

Gadamer, H-G. 1975. *Truth and method*. (1st South Asian Edition 2005. Translated and edited by Garrett Barden and John Cumming). New York: Seabury Press. (This edition 2004.Translation revised by Weinsheimer & Marshall, D. London: Continuum.)

Gibbons, M. & Gummett, P. (eds.). 1984*. Science, Technology and Society Today.* Manchester: Manchester University Press.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. & Trow, M. (eds.). 1994. *The New Production of Knowledge: the Dynamics of Science and Research in Contemporary Societies.* London: SAGE.

Godin, B. & Gingras, Y. 2000. 'What is scientific and technological culture and how is it measured: A multi-dimensional model'. *Public Understanding of Science*,9 (1), 43-58.

Habermas, J. 1966.'Verwissenschaftliche politik in demokratischer gesellschaft', in Krauch, H. & Dickinson, R. (eds.). *Fostchungsplanung*. Munchen: Oldenbourg, pp. 130-44.

Hans-Peters, P. 2008. 'Scientists as public experts', in Bucchi, M. & Trench, B. (eds.). 2008. *Handbook of public communication of science*. London and New York: Routledge.

Haraway, D. 2016. *Staying with the Trouble*. London: Duke University Press.

Hecker, S., Richter, A. & Bonn, A. 2018. 'New dawn for citizen science in Germany', in Le Marec, J. & Schiele, B. (eds.). 2008. *Cultures of science*. Bibliothèque et Archives nationales du Quebéc. Dossier produced as part of the Les Journées internationales de la culture scientifique – Science and You – held in Montreal 4-6 May2017.

Hirsch, H. G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U. & Zemp, E. (eds.). 2008. *Handbook of Transdisciplinary Research*. New York: Springer Science & Business Media.

Hountondji, P. 2002. 'Producing knowledge in Africa today', in Coetzee, P. H. & Roux, A. P. J. (eds.). *Philosophy from Africa*. Oxford and New York: Oxford University Press, pp.501 – 507.

Huges, T. 2006. 'Culture and innovation', in Nowotny, H. (ed.). *Cultures of technology and the quest for innovation,* New York: Berghahn Books, pp.27 -38.

Jacques, M. 2012. *When China rules the world*. London: Penguin.

Jeppie, S. & Diagne, S. (eds.). 2008. *The meanings of Timbuktu*. Cape Town: HSRC Press.

Klein, J. Grossenbacher-Mansuy, W., Haberli, R., Bill, A., Scholz, R. & Welti, M (eds.). 2001. *Transdisciplinarity: joint problem solving among science, technology and society. An effective way for managing complexity*. Basel: Birkhauser Verlag.

Klein, J. 2004. 'Interdisciplinarity and complexity: An evolving relationship', in *Emergence, Complexity and Organization*. Special Double Issue, 6, (1-2), 2-10.

Klein, J. 2014. 'Discourses of transdisciplinarity: looking back to the future'. *Futures*, 63, 68-74.

Klein, N. 2019. *On fire: the (burning) case for a new green deal.* New York: Simon & Schuster

Lang, D., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. & Thomas, C. 2012. 'Sustain Transdisciplinary research in sustainability science: practice, principles, and challenges.' *Sci.* 7 (Supplement 1), 25–43 (accessed 10 March 2020).

Lanier, J. 2014. *Who owns the future?* London: Penguin Books.

Lovelock, J. 2009. *The vanishing face of Gaia: a final warning*. London: Allen Lane.

Lovelock, J. 2014. *A rough ride to the future.* London: Penguin Books.

Lovelock, J. 2019. *Novacene: the coming age of hyper intelligence*. London. Allen Lane.

Magala, T. (ed.). 2019. *Science. Technology. Innovation*. Pocket Data Book. @ National Research University Higher School of Economics.

Mann, C. 2012. *1493: uncovering the New World that Columbus created*. London: Vintage edition in 2012.

Mann, M. 2003. *Incoherent Empire*. London: Verso.

MASIS Report. European Commission. 2009. EUR 24039. Challenging Futures of Science in Society – Emerging trends and cutting-edge issues. Luxembourg: Publications Office of the European Union.

MASIS Report. European Commission. 2012. EUR 25251. Monitoring Policy and Research Activities on Science in Society in Europe (MASIS). Final synthesis report. Luxembourg: Publications Office of the European Union Monitoring Policy and Research Activities on Science in Society in Europe (MASIS).

Mason, P. 2015. *Post-capitalism: a guide to our future*. London: Penguin Books.

Max-Neef, M. 2005. 'Foundations of Transdisciplinarity'. *Ecological Economics*, 53, 5-16.

Mayer-Schönberger, V. & Cukier, K. 2013. *Big data: a revolution that will transform how we live, work and think.* London: John Murray Publishers.

McGregor, S. 2015. 'The Nicolescuian and Zurich Approaches to Transdisciplinarity'. *Integral Leadership Review*, April - June 2015, 6-16.

Medium Term Strategic Framework (MTSF). 2014. Government of South Africa, https://www.gov.za/sites/default/files/gcis_document/201409/mtsf2014-2019.pdf, accessed 5 March 2020.

Miller, J. 1983. 'Scientific literacy: a conceptual and empirical review'. *Daedalus*, 112 (2), 29-48.

Miller, J. 1998. 'The measurement of civic scientific literacy'. *Public Understanding of Science*, 7 (3), 203-223.

Millgram, E. 2015. *The Great Endarkenment: Philosophy for an Age of Hyperspecialization*. New York: Oxford University Press.

Mishra, P. 2017. *Age of anger: a history of the present*. London: Allen Lane.

MISTRA. 2014 (reprinted 2019.). *The Concept and Application of Transdisciplinarity in Intellectual Discourse and Research.* Du Plessis, H., Sehume, J. & and Martin, L. (eds.). Johannesburg: Mapungubwe Institute for Strategic Reflection.

Miyoshi, M. 2010. *Trespasses*. Durham and London: Duke University Press.

Monbiot, G. 2017. *How did we get into this mess?* London: Verso.

Munro, I. 2002. 'Empire: the coming of the control society'. *Ephemera: critical dialogues on organization*, 2 (2), 175-185.

Nabudere, D. 2011. *Afrikology, philosophy and wholeness: an epistemology*. Pretoria: AISA Press.

Nabudere, D. 2012. *Afrikology and transdisciplinarity: a restorative epistemology*. Pretoria: AISA Press.

NPC. 2011. 'National Development Plan: vision for 2030'. Government of South Africa. https://nationalplanningcommission.wordpress.com/the-national-development-plan/, accessed 13 March 2020.

National Research Council. 2009. *Learning Science in Informal Environments: People, Places, and Pursuits*. Washington DC: The National Academies Press.

Nicolescu, B. 2002. *Manifesto of Transdisciplinarity* (translated from the French by Karen-Claire Voss). New York: SUNY Press.

Nowotny, H. 2006. *Cultures of technology and the quest for innovation*. New York: Berghahn Books.

Nowotny, H., Scott, P. & Gibbons, M. 2001. *Re-thinking science: knowledge and the public in an age of uncertainty*. Cambridge: Polity Press Books.

United Nations Climate Change. 2016. Paris Agreement on Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, accessed 5 March 2020.

Parrika, J. 2015. *A geology of media*. Minnesota: University of Minnesota Press.

Pearce, F. 2006. *When the rivers run dry*. Auckland: Eden Project Books.

Pearce, F. 2007. *The last generation: how nature will take her revenge for climate change.* Auckland: Eden Project books.

Ramose, M. 2002. 'African Renaissance a northbound gaze', in Coetzee, P. H. & Roux, A. P. J. (eds.). *Philosophy from Africa*. Oxford and New York: Oxford University Press, pp. 600 - 610.

Rancière, J. 2011. *Staging the people: the proletarian and his double* (translated by David Fernbach) London: Verso.

Rifkin, J. 2000. *The age of access: how the shift from ownership to access is transforming capitalism.* London: Penguin Books.

Rifkin, J. 2014. *The zero marginal cost society: the internet of things, the collaborative commons, and the eclipse of capitalism*. New York: St. Martin's Griffen.

Scheufele, D. 2014. 'Science communication as political communication'. *Proceedings of the National Academy of Sciences (PNAS)*, September 16, 2014, 111 (Supplement 4) 13585-13592; first published September 15, 2014. https://doi.org/10.1073/pnas.1317516111, accessed 8 March 2020.

Science Engagement Strategy (SES). **2015.** Department of Science, Technology and innovation (DSI). Government of South Africa. https://www.saasta.ac.za/saasta_wp/wp-content/uploads/2017/11/Science_Engagement_Strategy-11.pdf, accessed 13 March 2020.

Science, Technology and Innovation White Paper (STI). 2019. Government of South Africa. https://www.dst.gov.za/images/2019/FINAL-White-Paper-to-Cabinet_11-March-2019.pdf, accessed 13 March 2020.

Shen, B. 1975. 'Scientific Literacy and the Public Understanding of Science', in Day, S. (ed.). *Communication of Scientific Information*. Basel: Karger, pp. 44-52.

Shrivastava, A. & Kothari, A. 2012. *Churning the earth: the making of global India.* New Delhi: Penguin.

Shumba, O. 1999. 'Critically interrogating the rationality of western science vis-à-vis scientific literacy in non-western developing countries'. *Zambezia* XXXVI (i), 55-75.

Siew, T. F., Aenis, T. & Spangenberg, J. H. 2016.'Transdisciplinary research in support of land and water management in China and Southeast Asia: evaluation of four research projects'. *Sustainable Science*, 11, 813-829.

Smith, A., Fressoli, M, & Thomas, H. 2014. 'Grassroots innovation movements: challenges & contributions', *Journal of Cleaner Production*, 63, 114-124.

Smith, B. 2018. *Practicing relativism in the Anthropocene: on science, belief and the humanities*. Open Press: http://openhumanitiespress.org/books/titles/practicing-relativism-in-the-anthropocene, accessed 21 October 2019.

Sorokin, P. 1985 (originally published in 1957 by Porter Sargent). *Social and cultural dynamics: a system of change in major systems of art, truth, ethics, law and social relationships*. Revised and abridged. New Brunswick: Transaction Inc Publishers.

Standing, G. 2010. *The precariat: the new dangerous class*. London: Bloomsbury.

Standing, G. 2012. *The Precariat: why it needs deliberative democracy. Open Democracy: free thinking for the world.* Published under a Creative Commons Attribution-Non-Commercial 3.0 license.

Standing, G. 2017. *The corruption of Capitalism: why rentiers thrive and work does not pay*. London: Biteback Publishing.

Stiegler, B. 2018. *The Neganthropocene*. London: Open Humanities Press.

Stiglitz, J. 2002. *Globalization and its discontents*. London: Penguin books.

Van Breda, J. & Swilling, M. 2018. 'The guiding logics and principles for designing emergent transdisciplinary research processes: learning experiences and reflections from a transdisciplinary urban case study in Enkanini informal settlement, South Africa'. *Sustainability Science*, 13 (42), 1-19.

Volckmann, R. 2009. 'Creativity and transdisciplinarity: an interview with Alfonso Montuori'. *Integral Review,* 5 (2), 273-287.

Weisman, A. 2013. *Countdown*. London: Little Brown.

Žižek, S. 2010. *Living in the end times*. London: Verso.

Žižek, S. 2016. *Disparities*. London: Bloomsbury.

NOTES

[i] Humanity's impact on the earth is so profound that scientists are proposing that the earth is entering a new geological unit within the Geological Time Scale. During the current epoch, the Holocene, we experienced 12,000 years of stable climate. However, since the last Ice Age in the current Quaternary period and the Cenozoic Era, which are high rankings in the division of time, we saw anthropogenic changes associated with erosion and sediment movements, colonialisation, agriculture, urbanisation,

ocean acidification and rampant industrial driven carbon emissions. This new unit on our current time scale is referred to as the Anthropocene. A 35 member Anthropocene Working Group's task team, chaired by Prof Jan Zalasiewicz, was set up by the British Geological Survey, to have the Anthropocene being identified as a new geological epoch on the same hierarchical level as the previous Pleistocene and Holocene epochs. The task team is looking at the geological divisions that are defined by a specific boundary between layers of rock – similar to the feature that identified the Holocene, isolated by looking at the two ice layers in a core taken from Greenland. Enough evidence on the impact of human activities was found to recommend, during the recent 35th International Geological Congress held in South Africa (29 August 2016), that a provisional recommendation be accepted that the Anthropocene concept is geologically real. This Anthropocene Working Group is now tasked to provide evidence of a geological 'signal' or geological 'spike' that can be used to scientifically justify an epochal change, and to be applied as a useful formal term for the scientific community. Prospective spikes include sediment formed by concrete, chicken bones, radioactive elements from nuclear bomb tests, tough unburned carbon spheres emitted by power stations, plastic pollution, aluminium and concrete particles and high levels of nitrogen and phosphate in soils derived from artificial fertilisers. At the same time, this term has already been proved useful to the global change research-community to trace the impact, for example, of human actions on the change in weather patterns we are currently experiencing.

[ii] The European Commission's Monitoring Policy and Research Activities on Science in Society in Europe (MASIS) 2012 report (www.masis.eu) stated that the 'science in society' paradigm in Europe is dominated by issues related to its role in favour of sustainable development as well as its role promoting the appropriate governance of science. Most significantly, the MASIS report states: *'Discussions and processes relating to the appropriateness of science in society should be inclusive and based on broad public and stakeholder engagement'.* It further states that: '… the Europe 2020 societal challenges can only be tackled of society is fully engaged in science, technology and innovation and it should be stressed that the dynamics of public and stakeholder engagement remains an important object for further research and experimentations'.

[iii] See: Arnold, Carrie. 'Enemies within'. *New Scientist*.,29 February 2020, pp. 36 -39. '*Viruses that have buried themselves in our DNA now occupy about 8 percent of our genome'.*

[iv] The 'Science and Technology White Paper' of the South African government, is available at https://www.dst.gov.za/images/2019/FINAL-White-Paper-to-Cabinet_11-March-2019.pdf.

[v] http://www0.sun.ac.za/scicom/wp-content/uploads/2018/06/2015_sci_engagement_strategy.pd

[vi] The National Council on Innovation Act, 1997 (Act No. 55 of 1997), provided the mandate for the National Advisory Council for Innovation (NACI, 2015) and provided NACI with a broad policy mandate by introducing the concept of the National System of Innovation (NSI). Innovation was also supported by the National Research and Development Strategy (NRDS) in 2002. The NRDS seeks to contribute towards socio-economic development by focusing on a set of 'technology platforms' and 'science missions'. The technology platforms are put in place for the advancement of biotechnology, information technology, technology for advanced manufacturing, technology for and from natural resource sectors, and technology for poverty reduction.

[vii] Interdisciplinarity is usually characterised by collaboration and the integration of concepts and methods (and in turn may lead to the creation of new concepts and knowledge). Transdisciplinarity takes this a step further and may represent a different kind of knowledge production, embracing both scientific and other types of knowledge and the involvement of a broader range of expertise, including, potentially, the end users of such research. A transdisciplinary research process links societal problem-solving with scientific knowledge production in a process of co-producing knowledge. 'Close interaction with societal actors that can make decisions or take action, or may be affected in the respective field is key. To overcome the knowledge-action gap, the approach includes stakeholders from the beginning (co-design), deliberates on normative target questions (e.g. 'What are more desirable futures?') and co-produces knowledge on how to reach these targets' (DSI White Paper, 2019: 70).

[viii] Gibbons's (1984) proposed Mode 1 and Mode 2 systems of knowledge production created a stir amongst science researchers since it indicated a shift towards a transdisciplinary approach and placed 'uncertainty' central within (consumer-driven) science investigations. Gibbons (1984: 22) identified two models or modes:

•'Mode 1' is the conventional, discipline-bound way of research, where knowledge '…is validated by the sanction of a clearly defined community of specialists' (Gibbons, 1994: 22).

•When one shifted outside the parameters established by accepted research paradigms and academically constructed disciplines, one started to work in 'Mode 2', or in a transdisciplinary mode.

[ix] To use the word 'cene' is in reference to the Greek word kainos (καινός), meaning 'new'.

[x] During September 2015, the European Citizen Science Association (ECSA) published its Ten Principles of Citizen Science:

1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project.
2. Citizen science projects have a genuine science outcome. For example, answering a research question or informing conservation action, management decisions or environmental policy.
3. Both the professional scientists and the citizen scientists benefit from taking part. Benefits may include the publication of research outputs, learning opportunities, personal enjoyment, social benefits, satisfaction through contributing to scientific evidence e.g. to address local, national and international issues, and through that, the potential to influence policy.
4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process. This may include developing the research question, designing the method, gathering and analysing data, and communicating the results.
5. Citizen scientists receive feedback from the project. For example, how their data are being used and what the research, policy or societal outcomes are.
6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for. However unlike traditional research approaches, citizen science provides opportunity for greater public engagement and democratisation of science.
7. Citizen science project data and meta-data are made publicly available and where possible, results are published in an open access format. Data sharing may occur during or after the project, unless there are security or privacy concerns that prevent this.
8. Citizen scientists are acknowledged in project results and publications.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience and wider societal or policy impact.
10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data sharing agreements, confidentiality, attribution, and the environmental impact of any activities.

[xi] During January 2015 the ETH Zürich and University of Zürich hosted a first official international meeting on the 'Challenges and Opportunities in Citizen Science'. The first citizen science conference was hosted a month later by the Citizen Science Association in San Jose, California (February 2015) in partnership with the annual AAAS conference. A well-attended Citizen Science Association conference, CitSci 2017, was held in Saint Paul, Minnesota, United States during May 2017.

[xii] Richard P. Suttmeier, Cong Cao and Denis Fred Simon. Summer 2006, *China's Innovation Challenge and the Remaking of the Chinese Academy of Sciences Innovations.* https://www.mitpressjournals.org/doi/pdf/10.1162/itgg.2006.1.3.78 (accessed 1 November 2019). For an expanded discussion, see Richard P. Suttmeier, Xiangkui Yao, and Alex Zixiang Tan, 2006, *Standards of Power? Technology, Institutions, and Politics in the Development of China's National Standards Strategy*, Seattle, WA: National Bureau of Asian Research.

[xiii] The Russian School of Transdisciplinarity (td-science.ru/index.php/history (accessed 3 November 2019).