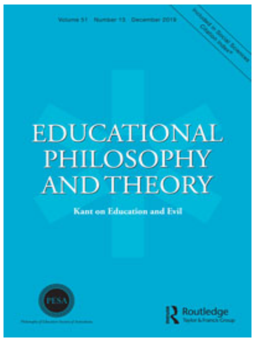

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EDITORIAL

Citizen science and post-normal science in a post-truth era: Democratising knowledge; socialising responsibility

Michael A. Peters and Tina Besley

Beijing Normal University, PR China

The question of how scientific theories, concepts and methods change over time is an enduring issue. Science, like all forms of intellectual activity, can undergo rapid and dramatic periods of change, as it did during the Newtonian period sometimes called the 'Scientific Revolution' of the 17th century. In other times, change has been very gradual. Questions of this nature occupied Thomas Kuhn who in *The Structure of Scientific Revolutions* (1970) argued for a philosophical conception of scientific change based on historical evidence that questioned the standard conservative history of science as the gradual cumulative development of discoveries that took place progressively over many generations. As is well known, Kuhn characterizes the history of science in terms of periods of 'normal science' followed by paradigm-changing 'revolutionary science'. Normal science is activity ruled by consensus over the problems, concepts and model solutions that together form a 'paradigm' or set of community understandings and procedures (a form of consensus). When problems begin to stack up and do not seem to be amendable to the accepted disciplinary solutions, they stand out as anomalies for current theory. Particularly recalcitrant anomalies come to constitute a crisis. The concept of 'revolutionary science' is Kuhn's answer to the death of the old paradigm and the inception of a new one. But paradigm change is not a rational process; scientists tend to want to hold on to the metaphysical core of the old paradigm even in the face of evidence (through face-saving ad hoc hypotheses) and only reluctantly give it up when the alternatives seem unassailable. Kuhn describes the process of paradigm as more like a 'gestalt switch' than a rational or evidential shift based on methodological procedures. Be that as it may, the history of science in the modern period has been dominated by Kuhn's conception and by those after him like Imre Lakatos and Larry Laudan who responded to Kuhn by describing the history of science in terms of progressive research programmes or a progression of problems. What seems common to these histories is that they all see science as an autonomous activity and picture change as a product largely of 'internal' developments (logic, problems, anomalies, etc.). Part of the novelty of Kuhn's analysis was in providing a naturalistic account of theory change that displaced positivist explanations in terms of rules of method governing verification that many saw as constitutive of rationality. Kuhn's legacy is undoubtedly a powerful one. His *Structure* book is one of the most cited books of all time.

Mladenović (2017, p. 1) tries to save Kuhn from relativism and irrationality by arguing that in line with American pragmatism he argues for the rationality of science as a form of *collective* rationality:

> At the purely formal level, Kuhn's conception of scientific rationality prohibits obviously irrational beliefs and choices and requires reason-responsiveness as well as the uninterrupted pursuit of inquiry. At the substantive, historicized level, it rests on a distinctly pragmatist mode of justification compatible with a notion of contingent but robust scientific progress.

CONTACT Michael Peters mpeters@bnu.edu.cn

Science changes through its own historical evolution through largely disciplinary mechanisms both formal and contingent, yet it also changes through historical forces that impact upon its conditions of possibility, through larger economic, social and technological historical factors sometimes referred to as 'social studies of science', an academic field that grown considerably since the 1970s that replaces epistemological questions with social ones.[1] In this vein, Collins and Evans (2010, p. 300) entertain the problem of legitimacy to ask a question about expertise rather than truth: 'If it is no longer clear that scientists and technologists have special access to the truth, why should their advice be specially valued?' And they probe the 'Problem of Extension': 'How far should participation in technical decision-making extend?' In addition, the approach from political economy proceeds from the assumption that technical change has radically altered economic development it has become essential to understanding the sources, nature and consequences of innovation in science and economic development.

In the current digital era, science faces three major kinds of changes and challenges that originate outside it. First, the accelerating effects of technology-driven developments that signal the critical term 'techno-science' is perhaps even more descriptively accurate than when it was introduced decades ago. On the standard view, technology, was always seen to be the *application* of science, but the traditional theory-practice understanding of the relationship of science and technology no longer holds and is often seen in an inverted relationship to science with technology dominant. Notably, Heidegger (1977) reversed the idea that modern science was the foundation of technology, arguing that the technological essence is the source of the form and function of science. Early usage by philosophers like Jean-Francois Lyotard and Bruno Latour used the term 'techno-science' to express a critical reaction against the theoretical conception of contemporary science that was philosophically blind to the importance of technology.

As a contemporary example, it might be argued that current US-China trade wars are driven by newly emergent conceptions of 'techno-development' and 'techno-nationalism' (Peters, 2018). For instance, the Office of the United States Trade Representative (USTR) released its report March, 2018 *Findings of The Investigation into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation Under Section 301 of The Trade Act of 1974*[2] indicating that the stakes involved in a collection of next generation strategic technologies including AI and quantum computing determine the future of scientific innovation in the global economy. As one commentator remarks:

> Techno-nationalism marries two trends that are central to our current historical moment. First, the remarkable acquisition of power through data and 'network effects' of just a few companies based mainly near San Francisco, and the escalating battle between these companies and Chinese rivals. And second, the decline of the post-1945 Western-led world order (https://www.bbc.com/news/technology-45370052).

Second, a set of co-evolving technologies have created 'convergence science' based on the 'nano-bio-info-cogno' paradigm that together define a creative synergy shaping both the next stage of science and an advanced stage of the knowledge society.[3] The National Science Foundation describes convergence science as:

> … a means of solving vexing research problems, in particular, complex problems focusing on societal needs. It entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyse scientific discovery and innovation. Convergence research is related to other forms of research that span disciplines—*transdisciplinarity, interdisciplinarity, and multidisciplinarity.*

Third, we are witnessing the emergence of 'post-normal science', a term introduced into the discourse by Funtowicz and Ravetz (1992) in the early 1990s, to signal the notional shift to an ecological systems perspective and the scientific management of uncertainty and of quality. Some critics interpreted this as the shift from 'truth' to 'quality assurance'. Fourth, there has been a rapid growth of what is referred to as Open Science or Science 2.0 that uses new technologies to increase and explore the democratization of and citizen participation in science (Peters & Heraud, 2015; Wals & Peters, 2018). As Halkay (2015) observes,

> The past decade has witnessed a sustained growth in the scope and scale of participation of people from outside established research organizations, in all aspects of scientific research. This includes forming research questions, recording observations, analysing data, and using the resulting knowledge. This phenomenon has come to be known as citizen science. While the origins of popular involvement in the scientific enterprise can be traced to the early days of modern science, the scale and scope of the current wave of engagement shifts citizen science from the outer margins of scientific activities to the centre—and thus calls for attention from policymakers.

The European Commissions' (2014) *Green Paper on Citizen Science* entitled 'Citizen Science for Europe: Towards a better society of empowered citizens and enhanced research' puts the argument powerfully in terms of a paradigm shift towards a more open research process where 'new participative and networked relationships promote the transformation of the scientific system, allowing collective intelligence and new collaborative knowledge creation, democratizing research and leading into emergence of new disciplines and connections.' Citizen science is but one manifestation of a larger movement for openness that has determining effects for science and its reception. The movement for Open Access Science such as Plan S,[4] is a recent initiative from cOAlition S backed by Science Europe to make full and immediate Open Access to publicly-funded research publications a reality by 1 January 2020 that will have a deep impact on the distribution of scientific knowledge and on current science publishing models. In one sense this is a pinnacle development of the OA movement which itself is part of the broader movement of openness in science and education (Peters, 2013, 2014; Peters & Britez, 2008; Peters & Roberts, 2012).

The fact that science, like economic development, is now technology-driven is a massive change with profound significance especially for science as a public endeavour. We can parse this idea further by reference to the US National Science Foundation that has been theorising 'convergent technologies' as a new techno-scientific synergy for well over a decade. The convergence is sometimes referred to as the 'nano-bio-info-cogno' paradigm that together have the power to define the next stage of science and an advanced knowledge society.[5] These technologies are not restricted to new digital technologies but embrace a set of converging technologies, including (briefly): 'Nano' - the branch of technology that deals with dimensions and tolerances of less than 100 nanometers, especially the manipulation of individual atoms and molecules; 'Bio', the exploitation of biological processes for industrial and other purposes, especially the genetic manipulation of microorganisms for the production of antibiotics, hormones, etc.; 'Cogno', the convergence of nano, bio and IT for brain science, sensing and mind control; 'Info', information technologies developing with new quantum computing. Sometimes referred to as 'NBIC technologies' (Nano, Bio, Information, Cognitive), this convergence is seen as a double-edged sword 'empowering both our creative and our destructive natures'.

The National Science Foundation (NSF) have many published reports exploring the convergence of the NBIC technologies including the chief application areas of (i) expanding human cognition and communication; (ii) Improving human health and physical capabilities; (iii) Enhancing group and societal outcomes (iv) Strengthening national security, and (v) Unifying science and education. Nanotechnology, biotechnology, information technology, and new technologies based in cognitive science (NBIC) signify an emerging harmony among the sciences, and a model of the 'unity of nature at the nanoscale' (e.g. Bainbridge, 2016; Bainbridge & Roco, 2006, 2016). We are told that recent advances in nanoscience and nanotechnology enable a rapid convergence of other sciences and technologies for the first time in human history with significant developments in biomedicine at the nanoscale (such as genetic engineering), nanoelectronics, and cognitive science, which holds the greatest promise but is the field least mature. (Significantly the claim is made that sociology and political science have not participated significantly in the development of cognitive science). The major claim is that 'science based on the unified concepts on matter at the nanoscale provides a new foundation for knowledge creation, innovation, and technology integration' (ibid.).

This 'convergence science' must be understood also by reference to the larger realities of Industry 4.0 and 'the fourth industrial revolution' that are closely related with the Internet of Things (IoT), Cyber Physical System(CPS), information and communications technology (ICT), Enterprise Architecture (EA), and Enterprise Integration (EI). Industry 4.0 is often referred to in terms of the integration of complex physical machinery and devices with networked sensors and software and as such represents 'a new level of value chain organization and management across the lifecycle of products' (Henning and Johannes). This rapid technological change is often conceived in terms of the power to *disrupt* economies and societies.

Brynjolfsson and McAfee (2014) in *The Second Machine Age* have commented that the computer revolution has huge potential for disrupting labour markets and reducing labour costs. They talk of the watershed in robotization and the corresponding increasing capacity and intelligence of digital technologies which has wider societal effects than solely altering the way science is practiced:

> digitization is going to bring with it some thorny challenges .... Rapid and accelerating digitization is likely to bring economic rather than environmental disruption, stemming from the fact that as computers get more powerful, companies have less need for some kinds of workers. Technological progress is going to leave behind some people, perhaps even a lot of people, as it races ahead (p. 11).

The focus on the political economy of digitalization is important for understanding the transformed environment within which science is now practiced. There is a *single planetary technical system* that enables access to global markets in instantaneous real time creating truly globally scaled markets that dwarf the scale of the first industrial/colonial system and exponentially speeds up all transactions. The single planetary system is an integrated system that includes the scientific community through global science publishing by the big eight and the larger networks they help comprise with university consortia and ranking agencies. A fundamental difference is that this single system perfected and refined reaching into every corner of the world no longer works on simple cause and effect and therefore is not a linear system but rather emulates natural systems to become dynamic and transformative, demonstrating the properties of chaotic and complex systems that at the same time increase volatility, interconnectivity and unpredictability.

The Chief Science Advisor during the last National government administration in New Zealand, Sir Peter Gluckman, gave an interesting speech at the Public Communication of Science and Technology Conference 2018, held in Dunedin, (3–6 April), entitled 'Knowledge brokerage in an age of rapid technological change.'[6] He reflected on his role as a 'broker' and science communicator between the science community and the policy community, two very different cultures which, as he also points out, are based on different processes and open to different influences. He notes also how science alone, contrary to popular opinion, 'will not resolve different world views' yet such world views often act as the schema through which people interpret data and evidence. He acknowledges that new disruptive science-driven technologies are rapidly growing – 'artificial intelligence, machine learning and big data, robotics, internet of things, autonomous vehicles, nanotechnology, gene editing, brain enhancement drugs, meiotic gene driven, bioelectronic implants, synthetic biology and geoengineering are some of the most obvious'. Together they increase the complexity of science and policy making and have the power to undermine democracy (Ed. or assist it). This is a new world of uncertainty especially in a 'post-trust' and 'post-truth' society: as he notes, 'The nature of the scientific method means that one can never absolutely prove anything to be completely safe. And no innovation is possible without some acceptance of uncertainty.' As a practicing scientist—a NZ paediatrician with an interest in endocrinology—Gluckman explains the dramatic changes to science in the last 30 years as a result of the digital revolution:

> The result of computational development on one hand (including the emergence now of big data) and the molecular sciences on the other have changed what science is possible. An increasing amount of science, is

> now framed within systems thinking which moves us from certainty to probabilistic approaches. As a result of these changes we are also moving from what's been called normal to post-normal science, where the science is complex and where there is a high values component that is often in dispute (p. 4).

It is surprising that in the year of the NZ Royal Society Centenary (2018) that he should use the term 'post-normal science' (PNS) and 'post-trust', with a clear set of references to 'post-truth' and Trump's anti-science policies, and his unilateral withdrawal from the Paris environmental accord. (Even in a world of uncertainty as government a spokes-person one has to be careful not to offend against supposed allies). Glucksman's argument is one for the enhanced role of science communication to mediate between the two specialised communities of science and policy. We were interested in his speech for another reason—for its contemporaneity and his use as the then Chief Scientist of PNS and 'post-truth'. Gluckman (2018) cautions us:

> But citizen science in whatever form is not enough. We need to take lessons from the language and scholarship of post-normal science: the answer must lie in concepts like extended peer review, co-design and co-production. These are critical but complex and controversial concepts but they will be a large part of the future of science.

The Fourth PNS conference 'Post-normal science as a movement**:** between informed critical resistance, reform and the making of futures' held in Barcelona, 15–17 November 2018 began with this quote from Gluckman (above) and provided the following briefing that is worth referring to in full:

> Science, as it stands today, faces a crisis of public and political trust, combined with an inner erosion of standards of quality and integrity. Scientific findings are increasingly recognised as neither as reliable nor reproducible as they used to be portrayed. Beliefs in and self-declarations of the disinterestedness of scientific endeavours, separated from vested interest, political agenda or social and cultural context are recognised as empirically and philosophically problematic. Scientific elites are, for better or for worse, challenged by an erosion of trust on a par with that experienced by political elites in modern societies. Scientific institutions charged with higher education face demands of high societal relevance and impact which they do not know how to meet and how to prepare for.
>
> This crisis on multiple fronts calls for a fundamental reform. Post-normal science (PNS) offers direction to such a reform, as a critical concept challenging mainstream practices of science, as an inspiration for new styles of research practice, and as an inspiration and support for new conventions of research quality assurance that better respond to the post-normal conditions of today's societal challenges. This multifaceted nature of PNS is both descriptive and normative. It provides a framework for describing and diagnosing urgent decision problems—post-normal issues—characterized by incomplete, uncertain or contested knowledge and high decision stakes, and critical reflection on how these characteristics change the relationship between science and governance. At the same time, PNS inspires a movement of critical resistance and reform towards a new style of scientific inquiry and practice that is reflexive, inclusive (in the sense that it seeks upstream engagement of extended peer communities) and transparent in regards to scientific uncertainty, ignorance, values and framings, and moving into a direction of democratisation of expertise.[7]

It is useful to list the themes that were to be discussed at PNS 4 that were designed in part to address Gluckman's concerns:

- PNS as a critical concept for informed resistance and reform (What strategies of resistance and what of reform or Reformation does PNS care about? What, when, where, why each of them? Resisting what, by/for/against whom, and why?)
- Ethics and matters of care in quantification, algorithms and big data (responsible quantification, use of quantitative evidence in policy making; post-normal perspectives on algorithms, big data, machine learning and AI)
- Tools and practices in knowledge quality assessment and extended peer communities (deliberation support tools for informed multi actor dialogues; which actors and how? Empowering marginalized actors)

- Post-normal literacy (building societal resilience to sloppy science, conspiracy theories, and post-truth phenomena; best practices for open science, quality assurance of extended facts)
- Puzzling value landscapes (responsibility, dignity, integrity, and other values)
- PNS in the making of futures (anticipation, path dependency, defending humanity)

Clearly, the issue of trust has become an outstanding issue, one that is paramount in the era of 'post-truth' when Trump's administration has encouraged a scepticism against science that some critics view as anti-science and a flagrant disregard for the concept of truth (Peters et al., 2018).[8] These conferences framings are significant for the ways they inform us of the concerns of practicing scientists in an era where science is up against 'alternative facts' and open to gross political interference and interpretation. It is these concerns that motivate Nick Enfield (2017)[9] writing in *The Guardian* to suggest:

> While we might debate the wisdom of trusting political insiders, the suspicion of specialists and experts has begun to contaminate a much bigger ecology of knowledge and practice in our society. The result is post-truth discourse. In our new normal, experts are dismissed, alternative facts are (sometimes flagrantly) offered, and public figures can offer opinions on pretty much anything.

Enfield documents the pro-truth countermovement with over 600 cities participating in the global March for Science on Earth Day in April 2017 with thousands signing the pro-truth pledge to share, honour and encourage truth.[10]

The term 'post-normal science' requires some background. Funtowicz and Ravetz (2003) make the statement that in policy world of risk and environment 'a new type of science—'post-normal'—is emerging.' They go on to make the comparison with traditional problem-solving science by reference to 'systems uncertainties and decision stakes':

> Postnormal science is appropriate when either attribute is high; then the traditional methodologies are ineffective. In those circumstances, the quality assurance of scientific inputs to the policy process requires an 'extended peer community', consisting of all those with a stake in the dialogue on the issue. Post-normal science can provide a path to the democratization of science, and also a response to the current tendencies to post-modernity (p. 739).

As Karpińska (2018) comments *everything* is now post-normal and the definition that Funtowicz and Ravetz gave almost 30 years ago 'is reaching the peak of its popularity.' Post-normal science as they proposed it was the scientific model on how to deal with policy-driven issues like global warming bringing together members of the science and policy communities and combining democratic consensus machinery with the pursuit of science: 'Funtowicz and Ravetz try to overtake these conflicts by reformulating the aim of knowledge from the truth to the quality of the epistemic process. They suggest expanding the research community to extended peer communities.' In exploring the origin of the concept, she cites Funtowicz and Ravetz's early paper (1992):

> One way forward would be to realize that the technological system that has created the problems cannot be simply adapted for achieving their solution. Then there would need to be a radical transformation of the science-based technology that is deployed on such global problems; we have described this as post-normal science. (Funtowicz & Ravetz, 1992, p. 972)

The situation for PNS has become more difficult with the rise of 'post-truth politics' as Rose (2018) indicates in his article 'Avoiding a Post-truth World: Embracing Post-normal Conservation'. He suggests that conservation science has always been post-normal and he encourages scientists to develop co-productive relationships with decision makers to harness narratives to engage with people on a personal level. He analyses the rise of post-truth politics as follows:

> In the aftermath of unexpected election results in the UK and USA, and threats to pull out of international environmental agreements, the science community has struggled with a decision-making environment that seems to undervalue the importance of scientific evidence. It has been claimed that selective, or biased, use of evidence may be enhanced by the rise of nationalistic governments across the globe (Ross & Jones,

> 2016), who put forward arguments in favour of their own citizens, even in the face of the global science-based accords such as the Paris Climate Change Agreement (Tollefson et al., 2016). According to some, decisions about conservation and the environment can also be post-truth (Begon, 2017) as policy-makers selectively use, or ignore, scientific evidence to support political arguments (p. 518).

In part, these arguments analysing the increasing politicized environment of conservation science underlies the collection *Sustainability Science: Key Issues* edited by Ariane Königand Jerome Ravetz as a textbook, as the blurb says, of 'how one might actively design, engage in, and guide collaborative processes for transforming human-environment-technology interactions, whilst embracing complexity, contingency, uncertainties, and contradictions emerging from diverse values and world views.'[11] In 'Flowers of resistance: Citizen science, ecological democracy and the transgressive education paradigm', an orienting chapter by Arjen E. J. Wals and myself, we outline the concept of ecological democracy and the contribution of citizen science to 'transgressive educational paradigm' (Wals & Peters, 2018). The book is divided into three parts: 'Embracing complexity and alternative futures: Conceptual tools and methods'; 'What might transformations look like? Sectoral challenges and interdependence'; and, 'Tracking, steering and judging transformation'. König in her introductory essay explains 'Sustainability as a transformative social learning process'.[12] In our chapter we noted the conceptual and historical link between citizen science and ecological democracy:

> From its development in the 1980s and 1990s Green Political Theory (GPT) or ecopolitics founded on the work of Dryzek (1987), Eckersley (1992), Plumwood (1993) and Dobson (1980), participatory democracy has been viewed as a central pillar and key value, often associated with descriptions of decentralization, grassroots political decision-making and citizen participation, 'strong democracy' (Barber, 1997) and increasingly with conceptions of deliberative democracy. The value of participatory or grassroots democracy also seemed to gel with a new ecological awareness, non-violence and the concern for social justice. Green politics favoured participatory and more recently deliberative democracy because it provided a model for open debate, direct citizen involvement and emphasized grassroots action over electoral politics.

Permitted the use of data controlled by governments and large corporations we might be entering a new era characterized by the cooperation and coordination of amateur and professional scientists and driven by 'big data'. Enhanced computing and computation power along with big and linked data demonstrate a promising mix of local and global, humans and machines, humans and nature in the transgressive pedagogical paradigm that moves beyond the old industrial scientific model of applied science based on the expert specialist. This relatively new transformative approach can be traced back to a post-normal science perspective (Ravetz, 2004) based on a set of principles:

1. *encouragement of citizens' involvement in science*: citizen science is a useful model for co-produced public good science that recognises that citizens need to have both 'voice' and agency in science matters, especially as it effects local environment, and increases the democratisation of science and reduces the cultural distance between the expert and the citizen furthering the aim of science communication of complex policy issues;
2. *recognition and support for multiple ways of knowing and different types of knowledge*: indigenous knowledge based on long term stewardship and cultural rights of environment, include multiple perspectives that involve spiritual values and 'environmental being as a way of life'; 'local knowledge' based on long term experience also has a strong role to play in on-going environmental assessment;
3. *improving sustainability requires social learning and deliberation between the multiple stakeholders/actors* affected environmental failure (scientists being one of many); and development of 'sensitive' peer review systems that represent 'other' stakeholders;
4. *requires a more activist kind of learning* that not only uses standard methodologies to map and monitor the local environment and generate accurate data by scientifically accepted

> methods but also takes concerted action as a form of collective responsibility in line with local council and government objectives.

The European Citizen Science Association (ECSA) have promoted high quality citizen science through sharing existing examples of good practice and developing practitioner guides to support the citizen science practitioner community to develop partnerships, share resources and experiences, and build capacity within the sector.[13] ECSA also offered ten principles adopted and modified by the Australian CSA:

10 Principles of Citizen Science

1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.
2. Citizen science projects have a genuine science outcome.
3. Citizen science provides benefits to both science and society.
4. Citizen scientists may participate in various stages of the scientific process.
5. Citizen scientists receive feedback from the project.
6. Citizen science, as with all forms of scientific inquiry, has limitations and biases that should be considered and controlled for.
7. Where possible and suitable, project data and meta-data from citizen science projects are made publicly available and results are published in an open access format.
8. Citizen scientists are suitably acknowledged by projects.
9. Citizen science programs offer a range of benefits and outcomes which should be acknowledged and considered in project evaluation.
10. The leaders of citizen science projects take into consideration legal and ethical considerations of the project.

https://citizenscience.org.au/10-principles-of-citizen-science/

This is a little too prescriptive, perhaps, and we ought not to institutionalise or ossify the movement so that it prevents organic change within the movement. Citizen science needs to acknowledge its philosophical origins in open science and pragmatic models based on the logic of community of inquiry after Dewey and Peirce. Watson and Floridi (2018) provide a useful analysis of Zooniverse, the world's largest citizen science web portal showing 'how information and communication technologies enhance the *reliability*, *scalability*, and *connectivity* of crowdsourced e-research, giving online citizen science projects powerful epistemic advantages over more traditional modes of scientific investigation'. In their introduction, they write:

> Experts and amateurs have been collaborating on so-called 'citizen science' projects for more than a century (Silvertown, 2009). Traditionally, such projects relied upon volunteers to participate in data *collection*. In more recent years, the spread of information and communication technologies (ICTs) has allowed users to become increasingly involved in data *analysis*. Early online citizen science initiatives made use of participants' spare processing power to create distributed computing networks to run simulations or perform other complex functions (Anderson, Cobb, Korpela, Lebofsky, & Werthimer, 2002). The latest wave of citizen science projects has replaced this passive software approach with interactive web platforms designed to maximise user engagement. Utilising fairly simple tools provided by well-designed websites, amateurs have helped model complex protein structures (Khatib et al., 2011a, b), map the neural circuitry of the mammalian retina (Kim et al., 2014), and discover new astronomical objects (Cardamone et al., 2009; Lintott et al., 2009). As of December 2015, citizen science project aggregator SciStarter links to over a thousand active projects (SciStarter, 2015).

Watson and Floridi (2018) talk of 'crowdsourced e-research' and seek the philosophical implications of this new brand. In their study of Zooniverse, they produce a Diagram of sociotechnical knowledge production in Zooniverse, noting 'how technology permeates every step in the knowledge production chain.'

They conclude:

> We cannot be certain just what scientific developments the future holds in store, but we can be confident that many of our next great discoveries will be made thanks to some complex partnership of minds and machines. Whether or not such results are the product of crowdsourcing, thorough investigation of this strange and remarkable methodology sheds new light on the varied modes of human knowledge. Clearly the time has come to endorse a sociotechnical turn in the philosophy of science that com- bines insights from statistics and logic to analyse the latest developments in scientific research (p. 760).

While more attention needs to be paid to the 'sociotechnical turn' it is important to note that there is a conception of citizen science that is based on a *dual accountability relationship* of science to democracy: (i) opening up science policy processes and promoting a responsiveness of science to the needs of citizens, while at the same time (ii) engaging citizens in communication about science and tutoring them in large-scale research projects through virtual education and collaborative participation in scientific research projects.

There is a related philosophical literature that discusses both democracy as the use of social intelligence to solve problems of practical interest, and the epistemic powers of democratic institutions, that has a long history in pragmatism going back at least to Dewey. There is a great deal of variety in epistemic approaches to democracy but that they are all derived from the value of free public discourse that epistemologically guides political practice (Estlund, 2008). For example, in Peirce's account of the logic of the 'community of inquiry' scientific inquiry is taken to be justified not because it is infallible but because it is *self-correcting*. For Peirce, the idea of truth is based on consensus reached in the long term by a community of inquirers. Peer production and crowdsourcing as modalities of collective intelligence are exemplified in the interactions between online participants who share and self-organize activities in decentralized ways that are often not dominated by the profit motive. They can be seen to embody Perice's ideals. Indeed, peer production has come about through the development of distributed and decentralized organizational forms that have not required financial incentives of markets or coercive obligations of bureaucracies and as such escape the distortions of the market, one of its major contributions in an age of sponsored corporate research. Peer production can be thought of as social innovation that has arisen as a result of internet-based networked systems and online platforms that broaden, deepen and extend the concept of 'peer' to include all 'stakeholders' in policy processes, including local citizens directly or indirectly affected by decisions. Increasingly, citizens will become active in science projects (some more than others) and also active in the science policy processes and its evaluation through the technology-mediated co-production of social goods (Peters & Heraud, 2015).

Notes

1. See Society for the Social Studies of Science and scholarly resources that constitute the field, http://www.4sonline.org/resources/journals
2. https://ustr.gov/sites/default/files/Section%20301%20FINAL.PDF
3. Convergence Research at NSF https://www.nsf.gov/od/oia/convergence/index.jsp; The Convergence Revolution http://www.convergencerevolution.net/
4. https://www.coalition-s.org/
5. Peters (2018) The Challenges of Technological Unemployment and the Future of Digital Society, keynote at Cultivation of Core Competencies in a Changing Technological Society', INEI 2018 Symposium, November 20-22 Beijing Norma University, The 11th International Network of Educational Institutes (INEI) Annual Symposium.
6. https://www.pmcsa.org.nz/wp-content/uploads/18-04-06-Knowledge-brokerage-in-an-age-of-rapid-technological-change.pdf
7. 'This fourth PNS symposium [PNS1 in Bergen, NO, PNS2 in Ispra, IT (summarized in a recent special issue of Futures) and PNS3 in Tübingen, DE (video presentations available here)] provides a platform to discuss and explore the guidance that post-normal science can offer in finding a way out of the present crisis in and around science.

8. The third PNS conference was devoted to issues of trust in a post-truth world: '"Post-truth" and a crisis of trust? Perspectives from post-normal science and extended citizen participation. This third PNS Symposium intends to provide a space for discussing the current predicament of declining trust, increasing complexity and uncertainty in the science-society interfaces by deploying a variety of critical framings including, but not limited to, those inspired by post-normal science.' It continues: 'Discussions of recent political events – most notably the presidential election in the United States and the referendum in the United Kingdom to (Br)exit the European Union -frequently refer to ideas of "post-truth", "post-evidence" or "post-factual" politics. In its ambiguity, the idea of a "post-truth" age manifests a crisis of trust in both democratic and scientific institutions. At the same time, it implies the untenable assumption that politics and policies were once, and should be again, based on a unique truth provided by science (comprising the whole spectrum of natural and social sciences, and humanities). Since the early 1990s, the post-normal science approach has been applied to issues in the science-society interfaces characterised by uncertainty and complexity, including a plurality of legitimate perspectives. These cases have been described in terms of uncertain facts, high stakes, disputed values and urgent decisions. In light of this, the conception of science as a privileged "act-provider" for governance seems increasingly unsatisfying and problematic', https://www.uib.no/svt/109437/%E2%80%98post-truth%E2%80%99-and-crisis-trust
9. https://www.theguardian.com/commentisfree/2017/nov/17/were-in-a-post-truth-world-with-eroding-trust-and-accountability-it-cant-end-well
10. https://www.protruthpledge.org/
11. https://www.routledge.com/Sustainability-Science-Key-Issues-1st-Edition/Konig-Ravetz/p/book/9781138659285
12. König provides a useful account of Sustainability Science at https://www.routledgetextbooks.com/textbooks/sustainability/sustainability_science.php
13. https://ecsa.citizen-science.net/taxonomy/term/205

ORCID

Michael A. Peters http://orcid.org//0000-0002-1482-2975
Tina Besley http://orcid.org/0000-0002-4377-1257

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