Biodigital Philosophy, Technological Convergence, and Postdigital Knowledge Ecologies

Michael A. Peters, Petar Jandrić, and Sarah Hayes

1 A Philosophy of Biodigitalism?

Anyone living through the last year of Covid-19—its first, second, and third waves—will understand pragmatically the new significance of the relationships between the biological and the technological and, specifically, two emerging paradigms. The first paradigm, 'bioinformationalism', draws a close association between viral biology on the one hand and information science on the other to critically discuss the parallel structure of epidemics and infodemics and the nature of conspiracy in a post-truth world (Peters et al. 2020a). It also investigates the political economy and the effects of bioinformational capitalism (Peters 2012). The second paradigm, 'biodigitalism', also refers to the mutual interaction and integration of information and biology. In particular, it investigates biological futures through biodigital technologies including molecular diversity, the *de novo* synthesis of DNA constructs, the engineering of biochemical pathways, and genomic construction (the synthesis of new life). The acquisition of novel biological diversity here includes DNA synthesis, 'shuffling', and bioprospecting, as well as efficient mass screening. The focus is on understanding and manipulation of

M. A. Peters
Beijing Normal University, Beijing, China
e-mail: mpeters@bnu.edu.cn

P. Jandrić (✉)
Zagreb University of Applied Sciences, Zagreb, Croatia

University of Wolverhampton, Wolverhampton, UK
e-mail: pjandric@tvz.hr

S. Hayes
University of Wolverhampton, Wolverhampton, UK
e-mail: sarah.hayes@wlv.ac.uk

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

M. A. Peters et al. (eds.), *Bioinformational Philosophy and Postdigital Knowledge Ecologies*, Postdigital Science and Education,
https://doi.org/10.1007/978-3-030-95006-4_1

biological systems in computational biology, in systems biology more generally, and in genomic medicine (National Research Council 2009).

The philosophical aspect is not simply bioethics, but also biopolitics (after Foucault), 'bioepistemologies' (or evolutionary theories of epistemology), and evo-ontologies (Peters and Jandrić 2019a, b). In broad terms, it focuses on the historical flash point where forces of biology and information come together to determine the paths of cultural co-evolution through the development of eco-cybernetic systems and its form of rationality in relation to Earth system governmentality. Covid-19 revealed that despite 30 years of the experience of reorganizing social life through the Internet, over 80 years since Alan Turing's 'universal machine' and some 50 years since the first UNIX operating system portable across multiple platforms, most countries—indeed, humanity as a whole—were unprepared for adopting and adapting to a digital way of life (Peters et al. 2021).

The extent of 'being digital/digital being' surprisingly demonstrated how dependent we had become on digital technologies and yet how unprepared we were for fail-safe digital systems in terms of communication, trade, education, and security. This dynamic is inherent to the 'hard to define; messy; unpredictable; digital and analog; technological and non-technological; biological and informational' post-digital condition, which is 'both a rupture in our existing theories and their continuation' (Jandrić et al. 2018: 895). Lockdown and social distancing strategies effectively shut down the 'real' economy rendering mass populations unemployed, keeping children away from schools, students from universities, families at home, and all away from cafés, bars, and restaurants. In particular, hospitality, tourism, travel and export higher education, all collapsed suddenly with no digital fallback (see Jandrić et al. 2020, 2021a, b). Media, especially around the 2020 US election, became increasing partisan and polarized (Peters et al. 2020a). The only institution that continued to function was the share market that boosted finance capital and created decoupling effects that seemingly denied the reality of ongoing massive unemployment and its social disruption.

While there might be interesting shared conceptual overlaps between biology and informatics, there are few examples yet of their full integration (see Williamson 2019a, b). At the same time, biodigitalism emerges as a new episteme concerned with the living—with *bios*—and the intersections between genetic and digital codes that continues to furnish the 'new biology'. These intersections start with technologies for the creation of synthetic life after the discovery of DNA in the 1950s and now culminate in modern biopolitics with its conceptual tools and technologies for the management of populations. Philosophers and political theorists following Foucault and Deleuze and Guattari inquired into the general problematic of exploring the complex set of relations between the dialectic of the *bios* and the *technē*. These inquiries are based on two main disciplinary trajectories: the rise of systematic biology with Carl Linnaeus at Uppsala in the late eighteenth century, and the concept of a digital programmable computer with Charles Babbage at Cambridge in the early nineteenth century. As Pasquinelli (2011: 51–52) puts it: 'What are the consequences of a computer-based understanding of cellular reproduction for the sphere of ecology and biodiversity?'

2 The Great Convergence

These questions intimate the evolving coevolution of two overlapping systems (*bios* and *technē*) that have accelerated interactions over the last couple of decades giving new meaning to 'the coming biology revolution' where new biology approaches 'depend on greater integration within biology, and closer collaboration with physical, computational, and earth scientists, mathematicians and engineers' (National Research Council 2009). It is exactly at this point that the notion of 'technological convergence' has a strong application with the development of nanotechnology that implies a new technoscientific synthesis at the nanolevel (Bainbridge and Roco 2016; Peters 2020a, b). In *The Age of Living Machines: How Biology Will Build the Next Technology Revolution* Susan Hockfield (2019) mentions Convergence 1.0, which is the convergence between physics and engineering that drove much of the innovation of the twentieth century including new technologies that are still evolving: radios, telephones, televisions, aircrafts, radar, nuclear power, computers, and the Internet. Convergence 2.0, which is the new convergence between biology and engineering that is occurring now, includes virus-built batteries, protein-based water filters, cancer-detecting nanoparticles, mind-reading bionic limbs, and computer-engineered crops.

The new convergences 2.0 and beyond are of a different order, suggesting a megaconvergence of genomic and information science at the level of code, leading to the 'Nano-Bio-Info-Cogno Paradigm' which has been one of the new bases of the US National Science Foundation in the last decade (Peters 2020a). In this context, we need a postdigital critical philosophy that examines the nature of these convergences and especially the convergence of information and genomic science at the nanolevel, linking it to techno-science, techno-politics, and techno-nationalism (Peters and Besley 2019). A central point of critique in the critical philosophy of convergence is the political economy of 'post-biological technocracy' and its tendency to 'numb' the biological self and creates a kind of digital obedience where Big Tech 'platform ontologies' know us better than we know ourselves (Peters 2020b; Peters and Jandrić 2019b).

Reports increasingly recognize the 'emergence of biodigitalism' as the coming horizon and examine a societal and economic future based on the merging of biology and digital technologies. A recent report in Policy Horizons Canada entitled Exploring Biodigital Convergence (2020) 'uses foresight to help the federal government build stronger policies and programs in the face of an uncertain future' and investigates the question—What happens when biology and digital technology merge?—from an economic perspective. The report addresses why biodigital convergence is occurring now and the characteristics and new capabilities arising from the biodigital systems. Kristel Van der Elst, Director General of Policy Horizons Canada, puts it this way:

> In the coming years, biodigital technologies could be woven into our lives in the way that digital technologies are now. Biological and digital systems are converging, and could change the way we work, live, and even evolve as a species. More than a technological

> change, this biodigital convergence may transform the way we understand ourselves and cause us to redefine what we consider human or natural. … Digital technologies and biological systems are beginning to combine and merge in ways that could be profoundly disruptive to our assumptions about society, the economy, and our bodies. We call this the biodigital convergence. (Van der Elst in Policy Horizons Canada 2020: 5)

Both ‘biodigital technologies’ and ‘biodigital convergence’ are useful concepts and related to the ‘Nano-Bio-Info-Cogno Paradigm’. The US National Science Foundation (NSF) have published reports exploring the convergence of the ‘NBIC technologies’ (‘nano-bio-info-cogno’) suggesting there that there is a new scientific ‘unity at the nanoscale’ (Bainbridge and Roco 2006: 49). The notion of ‘convergent technologies’—*the great convergence*—has guided NSF for over a decade, has been recognized and adopted also in Europe and China (Peters et al. 2021), and attracts much commentary from scholars around the world. However, the concept of ‘the biodigital convergence’ is used seemingly without prior knowledge of its use or its kindred concepts like ‘bioinformation’. With this in mind, we move on to explore the very foundations of the bioinformational convergence.

3 The Technologization of Bioinformation

For thousands of years, (natural) scientists have employed various analytical methods[1] to make sense of reality. The analytical method can be roughly divided into three stages. The first stage consists of problem posing and gathering of relevant information. The second stage is problem abstracting, which ends with an abstract ‘law of nature’ such as the Second Newton’s Law. In the third stage, abstract laws and principles are applied and tested, leading to their confirmation or falsification. There are various interpretations of this process (for instance, Popper vs. Kuhn), but this general structure of the analytic method has remained firmly in place for many centuries.

In the second part of the twentieth century computers have gained enough power to enable a numerical approach to scientific inquiry. The first stage still consists of problem posing and gathering of relevant information; these days, this translates into the creation of huge datasets often called Big Data. In the second stage, Big Data is manipulated using various numerical processes, often supported by artificial intelligences, leading again to abstract laws and principles. But now, artificial intelligences do not just process data towards a pre-determined problem. They also surface connections and relationships within data and identify new problems,

[1] Here, the term ‘analytical method’ refers to the mathematical distinction between analytical and numerical methods and should not be confused with other uses of the term analysis (such as analytic philosophy). ‘In mathematics, some problems can be solved analytically and numerically. An analytical solution involves framing the problem in a well-understood form and calculating the exact solution. A numerical solution means making guesses at the solution and testing whether the problem is solved well enough to stop.’ (Brownlee 2018)

previously unseen by human beings. In the third stage, abstract laws and principles are applied and tested, more often than not, using more Big Data and more artificial intelligences. This brings about a fundamental difference between analytical and numerical research. Since human beings are unable to process Big Data, algorithms have a lot of agency in all stages of research. This leads to a widely debated symmetry between human and nonhuman researchers (Jones 2018; Fuller and Jandrić 2019) and brings about the posthumanist shift from *using* computers to *collaborating with* computers.

In one direction, a strong reliance on numerical methods represents the digitalization of biology; in the opposite, equally important direction, it represents the biologization of information. On the 70th anniversary of Erwin Schrödinger's famous lecture 'What is life', Craig Venter gave a presentation 'What Is Life? A 21st Century Perspective' at Trinity College Dublin where he vividly outlined practical consequences of this bidirectionality:

> We can digitize life, and we generate life from the digital world. Just as the ribosome can convert the analogue message in mRNA into a protein robot, it's becoming standard now in the world of science to convert digital code into protein viruses and cells. Scientists send digital code to each other instead of sending genes or proteins. There are several companies around the world that make their living by synthesizing genes for scientific labs. It's faster and cheaper to synthesize a gene than it is to clone it, or even get it by Federal Express. (Venter 2012)

This marriage between analytical and numerical methods builds the basis of the bioinformational convergence and has important philosophical implications. Bioinformatics has not arrived from a sudden or artificial blend of the 'soft' or 'moist' *bios* and the 'hard' or 'cold' *technē*; instead, the *technē* is an inherent feature of the *bios*. To various extents, biology is digital information and digital information is biology; one cannot be divorced from the other. Humanity's newly acquired technological ability to deal with this dialectic now builds the basis of biodigitalism and biodigital technologies that represent a new revolutionary way forward where technology leads science.The ability to turn biology into digital code, and then to return digital code back into biology, offers much more than new theoretical insights. Just as importantly, it offers extended and up to recently unimaginable opportunities for tinkering with and actively transforming living organisms. This leads to numerous ethical dilemmas in bioinformational research (see Peters and Jandrić 2019a) such as the popular question of germline gene therapy 'which would allow the inserted gene to be passed to future generations'. This practice is deeply controversial. 'While it could spare future generations in a family from having a particular genetic disorder, it might affect the development of a fetus in unexpected ways or have long-term side effects that are not yet known.' Consequently, the US Government does not support research on human germline gene therapy (US National Library of Medicine 2018). These unintended consequences are not at all fictional. For instance, the first cloned mammal, Dolly the sheep, has lived a short life burdened with multiple diseases, and researchers are unsure whether her health problems are associated with cloning (Shiels et al. 1999).

Such technologization of biology, with its numerous practical capabilities, is the reason why biodigitalism is a wider concept than bioinformation. Furthermore, these practical capabilities cannot be thought of without a wide array of theoretical questions such as whether artificial intelligences can be understood as a form of life (see Fuller and Jandrić 2019; Savin-Baden 2021) and how should we treat the possible arrival of 'Hawking-inspired postdigital human beings created through self-designed evolution quicker than non-tampered (natural) evolution of human intelligence' (Peters and Jandrić 2019a; see Hawking 1996; Peters et al. 2020b). They also open up various long-term scenarios, such as Ray Kurzweil's (2005) vision of singularity in which humans and computers will form a sort of shared planetary intelligence. Summarizing these and other issues, Gillings et al. ask a crucial question:

> It seems inevitable that digital and biological information will become more integrated in the future. This scenario raises the question of how such an organic–digital fusion might become a symbiosis that coevolves through natural and artificial selection. In all symbioses, there is potential for exploitation and cheating [75], and this possibility has to be examined for the biological–technological fusion. (Gillings et al. 2016: 8)

These and related questions sit within new biodigital knowledge ecologies based on new relationships between biology and informatics. They include new understandings of life, including development of algorithmic non-carbon-based 'living' systems and human-machine self-evolution quicker than non-tampered (natural) evolution (Peters and Jandrić 2019a; see Hawking 1996; Peters 2020c). They require active engagement with continuous reconfigurations of relationships between biodigitalism and society. Biodigitalism is inherently Anthropogenic, so this engagement does not stop at human beings but extends towards all life forms—as can be seen from the recent example of the Covid-19 pandemic, our dietary practices are dialectically intertwined with humankind's collective health and well-being (O'Sullivan 2020). New knowledge ecologies are a 'part of the wider innovation of technocapitalism and can only really be understood in postdigital terms of posthumanism though biodigitalism—specifically how these two forces between them shape the future of human ontologies of what we can become' (Peters and Jandrić 2019b). Situated within bioinformational capitalism (Peters 2012), and co-developed by humans and machines as we write this chapter, the new knowledge ecologies further bring about perhaps the most fundamental shift in the typology of traditional scientific disciplines and their economy in the history of science.

4 Scientific Crises and Social Implications

In the background to biodigital reconfigurations of traditional scientific disciplines, there has been a growing concern that 'quality control has failed to keep pace with the growth of science' (Ravetz 2016). While biodigitalism, as a mutual interaction of information and biology, is bringing far reaching changes to these paths of cultural coevolution, there are issues of scientific credibility that 'are older than most junior faculty members' (Bishop 2019: 435). From concerns over reproducibility (Open Science Collaboration 2015), through to the abuse of metrics (Wilsdon 2016), to problems of peer review in publishing (Peters et al. 2016; Jandrić 2020a), an ongoing disquiet in these and other areas of integrity cannot be overlooked. This is a stream of infiltration to knowledge ecologies over time, where a pervasive lack of reproducibility has effects on what we can 'know'. Yet this situation has also become more complex as human beings have ceased to be able to process Big Data. Now that algorithms have so much agency in all stages of research, there are questions of reproducibility to be levelled at both human and non-human researchers together, given their close collaboration.

New knowledge ecologies therefore include a posthumanist angle which allows reflection on an ongoing credibility and culture crisis in research and academic scholarship. This crisis has spanned predigital and postdigital times, with a combination of factors including how our political economy has placed systems of control and rewards that have produced positivist incentives for researchers (Jandrić 2020b). Then there is the 'industrialized' nature of science and the global division of labour with its accompanying inequalities (Jandrić and Hayes 2019). Short-term contracts afforded to researchers and teachers, where renewal rests in the hands of principal investigators, also means that maintaining 'ideals of independence and integrity becomes increasingly difficult' (Ravetz 2016). We now face the enormous proliferation of scientific writing which remains unread in its original form (Jandrić and Hayes 2019), and a blurring of lines between politics, journalism, and science that has been particularly apparent during the Covid-19 crisis (Rose 2020; MacKenzie et al. 2021). Pressures on the use of science for policymaking have been enormous bringing the convergence of relationships across scientific disciplines and mutual interactions between information, biology, politics, and the economy to the attention of a global audience.

Sutton (2020) argues that the 'frantic pace of the 24-hour news cycle and competition from social media mean the bandwidth through which complex ideas must be relayed to the public is very narrow'. Additionally, when parliament is composed largely of graduates of the humanities and social sciences, 'quantitative methods of physical science have always been something of an afterthought'. Added to this are incentives for broadcasters to gain 'a catastrophising 10-second soundbite' rather than 'a level-headed exposition' concerning the 'challenges of various competing strategies' (Sutton 2020). Therefore, we should not excuse any government's scientific advisers 'funded by the public purse and bearing considerable social responsibility, from providing cynical interpretations of data, of questionable validity, and drawn from a weak evidence base, all in order to justify further restrictions' (Sutton 2020). Innovative ideas quickly become old news and a prioritization of novelty over replication has developed. While 'under these harsh conditions quality becomes instrumentalised' because 'impact' is the name of the game, even more concerning is the issue that perhaps those who engage in 'shoddy' or 'sleazy' science do not know what is in fact, sub-standard (Ravetz 2016).

Picking up on these issues, Bishop (2019: 435) reflects on the last four decades of her scientific career to observe that threats to reproducibility have been recognized but have remained unaddressed. Furthermore, 'many researchers persist in working in a way that is guaranteed not to deliver meaningful results'. Enormous social implications therefore now include some concepts that need to be unlearned and some skills that must be relearned in order to restore the legitimacy and integrity of science (Benessia et al. 2016). Given that biodigital convergence is surfacing new knowledge ecologies, this brings to the forefront questions concerning what our image of science is, or should be, in relation to posthumanist theory. Historical ideals concerned science in opposition with organized religion, with a turning point as recent as the 1960s in debates between Popper and Kuhn (Fuller and Jandrić 2019). The questions of quality and credibility however have only recently become dominant, given that 'during the "science wars", sociological critics attacked the epistemological foundations of science, but not the imperfections in its practice' (Ravetz 2016).

Now the biodigital convergence needs to be explored across all of the emerging ecologies of knowledge with questions and implications of scientific credibility considered alongside characteristics of the biodigital systems, such as democratization, decentralization, geographic diffusion, scalability, customization, and reliance on data (Policy Horizons Canada 2020). Bishop (2019: 435) argues that 'new forces' such as the field of metascience, documentation, and awareness of the issues may finally help to address irreproducibility, as 'we can no longer dismiss [these] concerns as purely theoretical'. These days 'social media enables criticisms to be raised and explored soon after publication'. In scientific publishing, 'more journals are adopting the registered report format, in which editors evaluate the experimental question and study design before results are collected'. Finally, those who fund research have introduced requirements 'that data and scripts be made open and methods be described fully' (Bishop 2019: 435). James Ball (2020: 219) makes another important point that many of the scientists, technologists, and entrepreneurs behind the Internet and major systems and scientific advances under discussion, are still alive. This in itself has implications for new philosophies of science that are inclusive of the pioneers who brought them into being.

5 Biodigital Knowledge Ecologies

New technological ability is leading postdigital science where biology as digital information, and digital information as biology, are dialectically interconnected. This bioinformational convergence simultaneously leads to convergence and divergence of research activities. Convergence: this unified ecosystem allows us to answer questions, resolve problems and build things that isolated disciplinary capabilities cannot. Divergence: this creates new pathways, opportunities, competencies, knowledge, technologies and applications. Policy Horizons Canada (2020) outlines three main ways that biodigital convergence is emerging.

Firstly, *a full physical integration of biological and digital entities* means that digital technology can be embedded into organisms, and biological components can exist as parts of digital technologies. This merging of 'the biological and digital are creating new hybrid forms of life and technology, each functioning in the tangible world, often with heightened capabilities' (Policy Horizons Canada 2020: 9). Secondly, *a coevolution of biological and digital technologies* emerges when advances in one domain generate major advances in the other, to enable progress that would be impossible otherwise. This could potentially lead to biological and digital technologies that are developed as integrated or complementary systems now that so many complex living systems 'are increasingly subject to examination and understanding by digital tools and applications such as machine learning' (Policy Horizons Canada 2020: 9). Thirdly, *a conceptual convergence of biological and digital systems* is a form of biodigital convergence that could reshape our framing and approach to biological and digital realms, facilitating the blending of the two (Policy Horizons Canada 2020: 10).

5.1 A Full Physical Integration of Biological and Digital Entities

Some implications of a full physical integration of biological and digital entities could include robots with biological brains and biological bodies with digital brains (Policy Horizons Canada 2020). Kevin Warwick (2010) looks at culturing neural tissue and embodying it in a mobile robot platform to essentially give a robot a biological brain. He suggests that for a long time the topic of Artificial Intelligence was concerned with getting machines to copy humans, which restricted both technical and philosophical development, while building machine brains that are far more powerful than human brains was left aside. Yet this potential future would mean that possibly conscious beings could outthink humans at every turn, posing extreme dangers to the future of humankind. Rather than claim that such a brain is definitely conscious, he instead raises questions about what consciousness really is (Warwick 2010: 233). Similar questions and speculations emerge across a range of contexts (see Peters and Jandrić 2019a, b). For instance, in *Postdigital Humans: Transitions, Transformations and Transcendence*, Maggi Savin-Baden (2021) explores a wider notion of 'what it means to be a human subject, and the extent to which the idea of the human subject is still useful'.

Whether such questions, in the light of scientific changes in the twenty-first century, now need different philosophical ideas from those upon which we have built our society thus far, are important considerations (Harari 2017; Peters 2020c, d; Savin-Baden 2021). These configurations of relationships between biology and informatics include new understandings of debates concerning identity and communication that are raised in the notion of 'biodigital bodies'. O'Riordan (2011: 308) points out that a shift can now be traced from biodigital fictions to biodigital practices, but this has arrived rather quietly, along with the rhetoric of convergence. Picking up on the implications of the circulation of personal genomes, she argues that:

> In the biodigital elites that are assembled around genome scanning and sequencing, the attempts to establish the circulation of individual genomic information as socially normative … involves the extraction of free labor in the service of biomedicine, the empowerment of consumers in accessing their genomic information, and the creation of technocultural capital to enhance the power of an individual's career value. However, it also creates a milieu in which biological dimensions of life become subject to norms of digital sociality. (O'Riordan 2011: 308)

O'Riordan's argument brings philosophical considerations to whether such a convergence affects fundamental changes to how meaning is made through communication: 'A constitutive dimension of media is a power to change the sites of production and consumption. Media, where bodies are represented and meanings are made about them, have an inscriptive power upon actual bodies.' (2011: 309) This leaves us with questions of what existing or new social issues, injustices or inequalities may be aggravated, or alternatively what positive visions are developing and how these might be improved.

5.2 A Coevolution of Biological and Digital Technologies

Deeper understandings and manipulations of biology are being enabled through digital technologies that were not possible only a few years ago; vice versa, biology is also informing new approaches in computing. Additionally, there is a 'blurring between what is considered natural or organic and what is digital, engineered, or synthetic' (Policy Horizons Canada 2020: 10). Digitalisation and the bio-based industries that are starting to make impacts in the chemicals and materials sectors provide examples. James Philp from the Directorate for Science, Technology and Innovation explains that: 'Engineering biology needs digitalisation and vice versa. The bioeconomy is wider than biotechnology, however. There are many other ways that converging technologies and digitalisation can be applicable to the bioeconomy.' (OECD 2020).

The bioeconomy concerns using renewable feedstocks to produce everyday goods and services but now encompasses a wide range of sectors and activities including chemicals, food, agriculture, dairy, forestry, pulp and paper, waste management and others. Therefore, the bioeconomy is now seen as a new means of production that will gradually replace fossil-based production and be consistent with the concept of a circular economy (Philp and Winickoff 2018). The combination of digital and biological transformation therefore has significant implications for companies as it changes the design and handling of production processes and their products. Working with the physical world as digital means that many companies now need to become technology businesses if they are to survive.

5.3 A Conceptual Convergence of Biological and Digital Systems

A conceptual convergence of biological and digital systems has far reaching implications in that it could see a shift away from vitalism: the belief that living and non-living organisms are fundamentally different because they are thought to be governed by different principles (Policy Horizons Canada 2020: 10). Biodigital convergence thus involves a rethinking of biology as providing both the raw materials and a mechanism for developing innovative processes to create new products, services, and ways of being (Policy Horizons Canada 2020: 14).

In a sense, biodigital convergence is altering humans into 'the next critical infrastructure sector' (Toffler Associates 2016). It is argued that the 'rate of growth implies a growing comfort with networked, wearable, and implanted devices—and our connectivity with them'. Currently available implantable Internet of Things (IoT) devices (pacemakers, defibrillators, and insulin pumps, etc.) are external electronic devices that supplement human lives. In progressing towards an Internet of Humans (IoH), we gain greater insight into who we are to help us to know what is happening beneath our skin and inside our minds. This deeper integration with technology could connect us even more firmly within a prospective biodigital network where artificial organs could be monitored and controlled remotely, brain wave technologies may allow people to control their devices simply by thinking about them, high tech e-skin (artificial skin) would allow users to project and control their smartphone on their body, and so on (Toffler Associates 2016; see also Williamson 2019b).

Then there are the aforementioned questions of scientific quality and whether advances in IoT might contribute to the challenge of reproducibility. For example, as synthetic biology develops as an engineering discipline, it faces new challenges with standardization and inconsistencies and aims for new forms of consistency compete with the arrival of new parts, methods, and experimental practices. McCarty (2019) points towards a pivot where, rather than expect research laboratories to conform (when they each do things their own way), 'a better solution may be to instead enhance the ways that data is collected and analyzed' by connecting Internet-enabled sensors to almost any piece of equipment:

> In synthetic biology, this means that lab equipment can be monitored to ensure that experimental parameters between runs are consistent. The digital data can also be readily accessed by members of the lab or shared with external collaborators. By seamlessly connecting laboratory equipment and pooling data in a single, online database, users can always go back after an experiment and pore through the data to determine sources of inconsistency in measurements. (McCarty 2019)

Such augmentation of existing equipment with IoT-enabled sensors may be difficult though, with huge amounts of generated data challenging to process and analyse (McCarty 2019).Questions are beginning to emerge from other disciplines too. Tal Bar (2020) asks: can we think of biodigital architecture as a *site of promise* for social change? The barriers perceived here are not so much technological though as ontological, this leading us towards more philosophical considerations. Currently biodigital architecture is perceived to burden itself with a 'calculated means of encasing bodies in efficient buildings when instead, could it use the endless processing and collecting capacities to ask questions from a different order'? Drawing on the work of Rosi Braidotti (2019a) on nomadic thinking and subjectivity, Bar reflects on the architect as a digital artisan, a scrap collector, a storyteller of bodies as data. Bar's reflection reaches beyond the universal skeletal data that furnishes the tables and charts of biodigital practice, redefining the collective. The biodigital challenge 'is an opportunity to connect us to the otherness already within and surrounding us, to rethink the boundaries between individual and collective already transcending the humanist binaries to reshape our habits, our habitats, our relationalities'. Therefore, Bar asks: 'What architectural models could we see emerging?' (Bar 2020). Taking a longer look back at the shifts that have emerged in relation to science and technology, as linked activities that co-evolve, helps develop an overview of this broader landscape of technoscience, biodigitalism, and bioeconomy.

5.4 *Technoscience, Biodigitalism, and Bioeconomy*

In the late twentieth and early twenty-first centuries, national research funding patters have changed from 'big science' physics projects to projects in biotechnology and the so-called 'new biology' (Dyson 2007). Following early success in the post-war period that played a crucial role with the development of the Internet, twenty-first century US federal research funding now focuses on public and private sector investment in areas such as microelectronics, robotics, biotechnology, and the investigation of the human genome. These areas are now increasingly seen as the underpinnings of the new economy. An early expression of this was given by Moore, Spencer, and Wessner in their joint preface to *Capitalizing on New Needs and New Opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies*:

> As we begin the twenty-first century, many believe that we are also witnessing the start of a new era—one where humankind will increasingly expand its understanding of the building blocks of life, and one which will rely on advanced information technologies to process, analyze, and share the results of such research. This era may well rest on what some call the new economy – that is, an economy where higher sustained growth rates are fed by productivity improvements made possible by the application of new knowledge and new technologies. This state of affairs depends on continued public and private sector investment in productivity-enhancing technologies. It also requires substantial and expanded investment in basic research. Increased allocations of public resources to research, though, are not sufficient; continued progress also depends on government participation in the maintenance of a policy framework that supports the development of new technologies. (Moore et al. 2001: 3)

The development of a public-private partnership where national research funds are used to provide an underpinning for the developing new economy has been a feature of US funding. In a philosophical sense, the paradigm shift from physics and the physical sciences to genomic science and the life sciences, combined with a twin emphasis on Internet and related digital technologies, indicates a number of aspects:

1. The shape and direction of the development and formation of the sciences (and knowledges) are to a large extent determined by public funding of research priorities.
2. Research priorities that influence the larger pattern of public and private sector partnerships reflect economic imperatives and the future direction of the economy.
3. The emphasis on biotechnology and information technology indicates the prominence of a technology-driven agenda or a technology-led science.
4. This new formation we refer to as the relatively new constellation of 'technoscience'.

'Technoscience', a term coined by the Belgium philosopher Gilbert Hottois in 1978 and adopted and used by Lyotard, Latour, Stiegler, Ihde, and others, approaches science and technology as linked activities that co-evolve. Hottois traces technoscience to Martin Heidegger and to Gaston Bachelard's materialism in the 1950s and places it in a tradition that significantly includes Donna Haraway and Karen Barad. In *The Question Concerning Technology* Heidegger (1977) reverses the traditional modern relation between science and technology and emphasizes *technē*. In the original Greek usage, *technē* is a concept that refers to arts, skills, and handicraft and also an assemblage of interacting techniques that demonstrate strategic knowledges in relation to economic and political goals. Vincent and Loeve (2018) mention the origin and development of the term:

> The term 'technoscience' gained philosophical significance in the 1970s but it aroused ambivalent views. On the one hand, several scholars have used it to shed light on specific features of recent scientific research, especially with regard to emerging technologies that blur boundaries (such as natural/artificial, machine/living being, knowing/making and so on); on the other hand, as a matter of fact 'technoscience' did not prompt great interest among philosophers. In the French area, a depreciative meaning prevails: 'technoscience' means the contamination of science by management and capitalism. Some even argue that 'technoscience' is not a concept at all, just a buzzword. In this chapter, on the contrary, we make the case for the constitution of a philosophical concept of technoscience based on the characterization of its objects in order to scrutinize their epistemological, ontological, political and ethical dimensions. (Vincent and Loeve 2018)

The significance of a semiological understanding of technology as a language based on a deep code that brings informatics in line with synthetic biology speaks to the transformation of science on public power and civil institutions. The outlines of this 'theory' of a technology-led science reunified at the nano-level and applicable to the human body and brain in the new neurocognitive sciences have gained traction. One of the most compelling accounts is offered by Braidotti. In *Posthuman Knowledge* she raises the issue that when we visit websites and seek to subscribe, we are routinely required to verify that we are in fact a human. This requirement 'assumes as the central point of reference the algorithmic culture of computational networks—not the human'. As such, 'the human has become a question mark' (Braidotti 2019b: 1). She argues that the complexities of 'posthuman times, and the posthuman subjects of knowledge constituted within them, are producing new fields of transdisciplinary knowledge' which she discusses under a theoretical framework of the critical posthumanities (Braidotti 2019a: 31). This includes exploration of the 'parameters that define a posthuman knowing subject, her scientific credibility and ethical accountability' (Braidotti 2019a: 31). This shifts the focus from not just a quantitative growth of areas of study and quantified non-human 'objects' of research, but towards a qualitative shift to provide new possible 'human' formations and results in patterns that frame 'missing peoples' whose 'minor' or nomadic knowledge is the breeding ground for possible futures (Braidotti 2019a: 53).

Braidotti (2019a: 37) argues from the point of view of the humanities for both 'royal science' formations and for multiple assemblages of 'minor science', and especially for the new critical posthumanities defined at the moment between 'ceasing to be and what we are in the process of becoming'. She makes the strong argument that 'with cognitive capitalism being tuned into bio-genetics and informational codes—there is nothing left for critical thinkers to do other than to pursue the posthuman' (Braidotti 2019a: 53). We agree with this orientation but think that 'critical reason' in this context itself needs a biodigital interpretation and is not consumed by the posthumanities. Our point is that posthumanism is but one form of biodigitalism that mediates both biohumanities and the digital humanities where is it not preoccupied with the tradition of the subject (the political subject, the economic subject) and subjectivity studies. Biodigitalism is also much more oriented to ecosystems and coordinated Earth systems (climate, food, energy) in the name of sustainability. While we accept that 'the critical posthumanities provide a diversified array of the changing perceptions and formations of the "human" in the posthuman era' (Braidotti 2019a: 53), we also want to see posthumanism as an emerging feature of biopolitics (immune-state), biosecurity, immunology, and bioterrorism. Braidotti suggests that the complex re-composition of minor science in the critical posthumanities is giving us a measure of what we are in the process of becoming. In addition, we want to put the posthumanities in a critical relationship to epistemological and historical shifts in science and to the emergence of technoscience as comprised of twin forces of new biology and the digital technologies, both of which determine cultural evolution.

Technoscience in the twenty-first century is very different from science in modernity. The shift from industrial science to digital technoscience comprises the rise of the new digital platform technologies (AI, deep learning, robotics, and quantum computing), the commercialization of research, the relationship to the neoliberal 'knowledge economy', the logic of performativity, the shift from Big Science to Big Data and finally to Big Tech (Lyotard 1984; Peters 1989, 2020a), and related shifts in a wide array of connected areas. This is a story of that emerges from the immediate aftermath of the Second World War, the conferences of the Macy Cybernetics Group, and the military investment in the beginnings of the Internet. 'Technoscience' has also created a discourse of 'technopolitics' as a critical reception and assessment of these technical tendencies (Peters 2020d, e).

In terms of a tentative simple typology we can entertain the hypothesis of a number of major epistemological shifts in the post-war period emphasizing new knowledge ecologies, technologies, and research fields, that reflect a set of technological convergences that integrate, multiply, expand, broaden, and synthesize existing fields in genomic and information science. These can be envisioned as a series of compressed historical overlays which in large measure result from strategic national political and economic imperatives defined through patterns of public-private research and funding arrangements. Such a view would also encompass China's emergence as a techno-state and its investments in a range of 5G and 6G technologies including deep learning, AI, quantum computing and so on. One possible take on this typology is as follows:

1. Industrial science to postmodern technoscience.
2. Posthumanism and new materialism.
3. Postdigital science and education.
4. Bioinformational capitalism.
5. Biodigital technologies and the bioeconomy.

'Biodigital technologies' help to initiate and to articulate an emergent form of bioeconomy that is self-renewing in the sense that it can change and renew the material basis for life and economy as well as re-evaluate and alter the code to program itself. There are accordingly two major forms in the political economy of bioeconomy—capitalist and socialist. Both are transformed in a data-intensive 'circular' bioeconomy that can create a new combinatorial synthetic material base of genetically enhanced plants, animals, insects, and microorganisms in controlled and experimental artificial and augmented environments. Both systems are theoretically able to this with a much-reduced labour force so that labour is no longer a determining formal factor of production. The shift to algorithmic agricultural systems can also utilize forms of augmented intelligence, and thus come to depend more and more on highly specialized forms of scientific labour. The novel and critical aspect of long-term prospects for bioeconomy developed through biodigital technologies is to engineer environmental self-renewal that becomes the basis of long-term sustainability.

6 Conclusion

The great convergence between biology and information creates complex, interconnected reconfigurations at all levels of theory and practice. Starting from biodigital philosophy and bioepistemology, and passing through biodigital technoscience and the bioeconomy, this chapter has arrived to strategic national, political, and economic imperatives and patterns of public-private research and funding arrangements—to conclude with the ways that the biopolitics and bioeconomy are shaping biodigital philosophy and bioepistemology. To break this full circle into more manageable units of analysis, we used Policy Horizons Canada's (2020) classification of biodigital convergence into sub-areas such as a full physical integration of biological and digital entities, a coevolution of biological and digital technologies, and a conceptual convergence of biological and digital systems. We classified the main trends in the paradigm shift from physics to the life sciences, and we also summed up some major epistemological shifts towards new biodigital technoscience.

While these classifications have indeed been helpful in our analyses, biodigital phenomena stubbornly escape our attempts at categorization—speaking of one element (e.g., bioepistemology) always implies speaking about all others (technoscience, biopolitics, bioeconomy…). Biodigital knowledge ecologies are theoretical and practical (praxis); scientific and technical (technoscience); analog and digital (postdigital); biological and informational (bioinformational); and political and economic (bioinformational capitalism). Biodigital knowledge ecologies are much more than listed elements, and they also contain various combinations of listed and unlisted elements (e.g., biodigital technoscience). Looking at scale, biodigital knowledge ecologies scale from nanolevel (1 nm is one billionth of a meter or 0.000000001 m) to planetary level (Earth diameter is 12,742 km). Thus, biodigital knowledge ecologies involve various units of analysis from DNA and viruses, though the individual (post)human subject, to the Earth's ecosystem. Biodigital knowledge ecologies are individual and collective (biopolitics) and therefore normative (bioethics).

Such scalability, interconnectedness, and complexity make biodigital knowledge ecologies difficult to understand and work with. Yet their messiness, often accompanied by unpredictability, is inherent to our postdigital condition (Jandrić et al. 2018: 895) and invites ecological thinking. According to Fawns et al. (2020), 'ecologies have no clear beginning or end'. Therefore, biodigital knowledge ecologies should not be understood as snapshots into our reality but as sets of overlapping continua including animate-inanimate matter; past-present-future; epistemology-politics-economy; and many others. An important continuum is individual-collective responsibility. According to Lorraine Code, ecological thinking implies that 'people singly and collectively—indeed, *singly* because collectively—are *responsible* for what and how they know, on an understanding of responsibility that is as epistemological as it is ethical and political' (Code 2006: ix) (emphasis from the original). Developing this chapter is our responsibility as authors, reflecting on this chapter is the responsibility of its reader, and further development of biodigital knowledge ecologies is a responsibility shared among us.

Our current understanding of biodigital knowledge ecologies shows the uneven development of disciplinary formations. The fields grow at different rates and in different directions in connection with the full economy of disciplinary fields, applying, adopting and adapting technical developments from related subject areas, to produce new constellations and new knowledge ecologies. The new knowledge ecologies of the twenty-first century offer biodigitalism as a new evolutionary constellation that changes our understanding of causation, explanation, and history while also defining a new biopolitics of identity where the philosophy of race, class, gender, and intelligence meets genomics and information.

Acknowledgement This chapter was first published as Peters, M. A., Jandrić, P., & Hayes, S. (2021a). Biodigital Philosophy, Technological Convergence, and New Knowledge Ecologies. *Postdigital Science and Education, 3*(2), 370–388. https://doi.org/10.1007/s42438-020-00211-7.

References

Bainbridge, W. S., & Roco, M. C. (Eds.). (2006). *Managing Nano-bio-info-Cogno innovations: Converging Technologies in Society*. Dordrecht: Springer.

Bainbridge, W. S., & Roco, M. C (2016). Science and technology convergence: with emphasis for nanotechnology-inspired convergence. *Journal of Nanoparticle Research, 18*, 211. https://doi.org/10.1007/s11051-016-3520-0.

Ball, J. (2020). *The system: Who owns the internet, and how it owns us.* London: Bloomsbury.

Bar, T. (2020). Rethinking the individual–collective divide with biodigital architecture. *Architecture and Culture.* https://doi.org/10.1080/20507828.2020.1792202.

Benessia, A., Funtowicz, S., Giampietro, M., Pereira, Â. G., Ravetz, J. R., Saltelli, A., Strand, R., & Van der Sluijs, J. P. (2016). *Science on the verge*. Tempe, AZ and Washington, DC: Consortium for Science, Policy & Outcomes.

Bishop, D. (2019). Rein in the four horsemen of irreproducibility. *Springer Nature, 568*, 435.

Braidotti, R. (2019a). A theoretical framework for the critical posthumanities. *Theory, Culture & Society, 36*(6), 31–61. https://doi.org/10.1177/2F0263276418771486.

Braidotti, R. (2019b). *Posthuman knowledge*. Cambridge: Wiley.

Brownlee, J. (2018). Analytical vs numerical solutions in machine learning. Machine Learning Mastery, 13 April. https://machinelearningmastery.com/analytical-vs-numerical-solutions-in-machine-learning/. Accessed 20 November 2021.

Code, L. (2006). *Ecological thinking: the politics of epistemic location*. Oxford: Oxford University Press.

Dyson, F. (2007). Our biotech future. The New York Review, 19 July. https://www.nybooks.com/articles/2007/07/19/our-biotech-future/. Accessed 22 October 2020.

Fawns, T., Aitken, G., & Jones, D. (2020). Ecological teaching evaluation vs the Datafication of Quality: Understanding Education with, and Around, Data. *Postdigital Science and Education, 3*(1), 65–82. https://doi.org/10.1007/s42438-020-00109-4.

Fuller, S., & Jandrić, P. (2019). The Postdigital human: making the history of the future. *Postdigital Science and Education, 1*(1), 190–217. https://doi.org/10.1007/s42438-018-0003-x.

Gillings, M. R., Hilbert, M., & Kemp, D. J. (2016). Information in the biosphere: biological and digital worlds. *Trends in Ecology & Evolution, 31*(3), 180–189. https://doi.org/10.1016/j.tree.2015.12.013.

Harari, Y. N. (2017). Reboot for the AI revolution. *Nature, 550*(7676), 324–327. https://doi.org/10.1038/550324a.

Hawking, S. (1996). Life in the universe. https://www.hawking.org.uk/in-words/lectures/life-in-the-universe. Accessed 7 October 2021.

Heidegger, M. (1977). *The question concerning technology, and other essays.* Trans. W. Lovitt. San Francisco: HarperCollins.

Hockfield, S. (2019). *The age of living machines: how biology will build the next technology revolution*. New York and London: W. W. Norton & Company.

Jandrić, P. (2020a). A peer-reviewed scholarly article. *Postdigital Science and Education, 3*(1), 36–47. https://doi.org/10.1007/s42438-020-00202-8.

Jandrić, P. (2020b). Postdigital research measurement. *Postdigital Science and Education, 3*(1), 15–26. https://doi.org/10.1007/s42438-020-00105-8.

Jandrić, P., & Hayes, S. (2019). The postdigital challenge of redefining education from the margins. *Learning, Media and Technology, 44*(3), 381–393. https://doi.org/10.1080/17439884.2019.1585874.

Jandrić, P., Bozkurt, A., McKee, M., Hayes, S. (2021b). Teaching in the Age of Covid-19 - A Longitudinal Study. *Postdigital Science and Education, 3*(3), 743–770. https://doi.org/10.1007/s42438-021-00252-6.

Jandrić, P., Hayes, D., Truelove, I., Levinson, P., Mayo, P., Ryberg, T., Monzó, L. D., Allen, Q., Stewart, P. A., Carr, P. R., Jackson, L., Bridges, S., Escaño, C., Grauslund, D.,Mañero, J., Lukoko, H. O., Bryant, P., Fuentes Martinez, A., Gibbons, A., Sturm, S., Rose, J., Chuma, M. M., Biličić, E., Pfohl, S., Gustafsson, U., Arantes, J. A., Ford, D. R., Kihwele, J. E., Mozelius, P., Suoranta, J., Jurjević, L., Jurčević, M., Steketee, A., Irwin, J., White, E. J., Davidsen, J., Jaldemark, J., Abegglen, S., Burns, T., Sinfield, S., Kirylo, J. D., Batarelo Kokić, I., Stewart, G. T., Rikowski, G., Lisberg Christensen, L., Arndt, S., Pyyhtinen, O., Reitz, C., Lodahl, M., Humble, N., Buchanan, R., Forster, D. J., Kishore, P., Ozoliņš, J., Sharma, N., Urvashi, S., Nejad, H. G., Hood, N., Tesar, M., Wang, Y., Wright, J., Brown, J. B., Prinsloo, P., Kaur, K., Mukherjee, M., Novak, R., Shukla, R., Hollings, S., Konnerup, U., Mallya, M., Olorundare, A., Achieng-Evensen, C., Philip, A. P., Hazzan, M. K., Stockbridge, K., Komolafe, B. F., Bolanle, O. F., Hogan, M., Redder, B., Sattarzadeh, S. D., Jopling, M., SooHoo, S., Devine, N., & Hayes, S. (2020). Teaching in the age of Covid-19. *Postdigital Science and Education, 3*(2), 1069–1230. https://doi.org/10.1007/s42438-020-00169-6.

Jandrić, P., Knox, J., Besley, T., Ryberg, T., Suoranta, J., & Hayes, S. (2018). Postdigital science and education. *Educational Philosophy and Theory, 50*(10), 893–899. https://doi.org/10.1080/00131857.2018.1454000.

Jandrić, P., Hayes, D., Levinson, P., Lisberg Christensen, L., Lukoko, H. O., Kihwele, J. E., Brown, J. B., Reitz, C., Mozelius, P., Nejad, H. G., Fuentes Martinez, A., Arantes, J. A., Jackson, L., Gustafsson, U., Abegglen, S., Burns, T., Sinfield, S., Hogan, M., Kishore, P., Carr, P. R., Batarelo Kokić, I., Prinsloo, P., Grauslund, D., Steketee, A., Achieng-Evensen, C., Komolafe, B. F., Suoranta, J., Hood, N., Tesar, M., Rose, J., Humble, N., Kirylo, J. D., Mañero, J., Monzó, L. D., Lodahl, M., Jaldemark, J., Bridges, S. M., Sharma, N., Davidsen, J., Ozoliņš, J., Bryant, P., Escaño, C., Irwin, J., Kaur, K., Pfohl, S., Stockbridge, K., Ryberg, T., Pyyhtinen, O., SooHoo, S., Hazzan, M. K., Wright, J., Hollings, S., Arndt, S., Gibbons, A., Urvashi, S., Forster, D. J., Truelove, I., Mayo, P., Rikowski, G., Stewart, P. A., Jopling, M., Stewart, G. T., Buchanan, R., Devine, N., Shukla, R., Novak, R., Mallya, M., Biličić, E., Sturm, S., Sattarzadeh, S. D., Philip, A. P., Redder, B., White, E. J., Ford, D. R., Allen, Q., Mukherjee, M., & Hayes, S. (2021a). Teaching in the Age of Covid-19—1 Year Later. *Postdigital Science and Education, 3*(3), 1073–1223. https://doi.org/10.1007/s42438-021-00243-7.

Jones, C. (2018). Experience and networked learning. In N. Bonderup Dohn, S. Cranmer, J. A. Sime, M. de Laat, & T. Ryberg (Eds.), *Networked learning: Reflections and challenges* (pp. 39–56). Berlin: Springer International. https://doi.org/10.1007/978-3-319-74857-3_3.

Kurzweil, R. (2005). *The singularity is near: When humans transcend biology*. New York: Viking.

Lyotard, J-F. (1984). *The postmodern condition: A report on knowledge*. Trans. G. Bennington and B. Massumi. Minneapolis, MN: University of Minnesota Press.

MacKenzie, A., Rose, J., & Bhatt, I. (Eds.). (2021). *The Epistemology of Deceit in a Postdigital Era: Dupery by Design*. Cham: Springer.

McCarty, N. (2019). Synthetic biology and reproducibility meet on the internet (of things). Synbiobeta, 7 January. https://synbiobeta.com/synthetic-biology-and-reproducibility-meet-on-the-internet-of-things/. Accessed 25 November 2021.

Moore, G. M., Spencer, W., & Wessner, C.W. (2001). Preface. In C. W. Wessner (Ed.), *Capitalizing on New Needs and New Opportunities: Government-Industry Partnerships in Biotechnology and Information Technologies* (pp. 1–13). Washington, DC: The National Academies Press. https://doi.org/10.17226/10281.

National Research Council. (2009). *A new biology for the 21st century (p. 10.17226/12764)*. Washington, DC: The National Academies Press.

O'Riordan, K. (2011). Revisiting digital technologies: Envisioning biodigital bodies. *Communications, 36*(3), 291–312. https://doi.org/10.1515/comm.2011.015.
O'Sullivan, V. (2020). Non-human animal trauma during the pandemic. *Postdigital Science and Education, 2*(3), 588–596. https://doi.org/10.1007/s42438-020-00143-2.
OECD. (2020). *The digitalisation of science, Technology and Innovation: Key Developments and Policies*. Paris: OECD. https://doi.org/10.1787/b9e4a2c0-en.
Open Science Collaboration. (2015). Estimating the reproducibility of psychological science. *Science, 349*(6251), aac4716. https://doi.org/10.1126/science.aac4716.
Pasquinelli, M. (2011). Four regimes of entropy: for an ecology of genetics and biomorphic media theory. *The Fibreculture Journal*, FCJ-117, 51–68.
Peters, M. A. (1989). Techno-science, rationality and the university: Lyotard on the 'postmodern condition'. *Educational Theory, 39*(2), 93–105. https://doi.org/10.1111/j.1741-5446.1989.40000.x.
Peters, M. A. (2012). Bio-informational capitalism. *Thesis Eleven, 110*(1), 98–111. https://doi.org/10.1177/2F0725513612444562.
Peters, M. A. (2020a). Critical philosophy of technological convergence: Education and the Nano-bio-info-Cogno paradigm. In M. Stocchetti (Ed.), *The Digital Age and Its Discontents* (pp. 235–252). Helsinki: Helsinki University Press. https://doi.org/10.33134/HUP-4-12.
Peters, M. A. (2020b). A map of technopolitics: Deep convergence, platform ontologies, and cognitive efficiency. *Thesis Eleven, 158*(1), 117–140. https://doi.org/10.1177/2F0725513620928812.
Peters, M. A. (2020c). Posthumanism, platform ontologies and the 'wounds of modern subjectivity'. *Educational Philosophy and Theory, 52*(6), 579–585. https://doi.org/10.1080/00131857.2019.1608690.
Peters, M. A. (2020d). Platform ontologies, the AI crisis and the ability to hack humans 'An algorithm knows me better than I know myself'. *Educational Philosophy and Theory, 52*(6), 593–601. https://doi.org/10.1080/00131857.2019.1618227.
Peters, M. A. (2020e). *Wittgenstein, anti-foundationalism, Technoscience and philosophy of education.* London: Routledge.
Peters, M. A., & Besley, T. (2019). Critical philosophy of the Postdigital. *Postdigital Science and Education, 1*(1), 29–42. https://doi.org/10.1007/s42438-018-0004-9.
Peters, M. A., & Jandrić, P. (2019a). AI, human evolution, and the speed of learning. In J. Knox, Y. Wang, & M. Gallagher (Eds.), *Artificial Intelligence and Inclusive Education: speculative futures and emerging practices* (pp. 195–206). London: Springer Nature. https://doi.org/10.1007/978-981-13-8161-4_12.
Peters, M. A., & Jandrić, P. (2019b). Posthumanism, open ontologies and bio-digital becoming: response to Luciano Floridi's Onlife Manifesto. *Educational Philosophy and Theory, 51*(10), 971–980. https://doi.org/10.1080/00131857.2018.1551835.
Peters, M. A., Jandrić, P., & Hayes, S. (2021). Biodigital Technologies and the Bioeconomy: The Global New Green Deal? *Educational Philosophy and Theory.* https://doi.org/10.1080/00131857.2020.1861938.
Peters, M. A., Jandrić, P., Irwin, R., Locke, K., Devine, N., Heraud, R., Gibbons, A., Besley, T., White, J., Forster, D., Jackson, L., Grierson, E., Mika, C., Stewart, G., Tesar, M., Brighouse, S., Arndt, S., Lazariou, G., Mihalia, R., Bernade, L., Legg, C., Ozolins, J., Roberts, P. (2016). Towards a philosophy of academic publishing. *Educational Philosophy and Theory, 48*(14), 1401–1425. https://doi.org/10.1080/00131857.2016.1240987.
Peters, M. A., McLaren, P., & Jandrić, P. (2020a). A viral theory of post-truth. *Educational Philosophy and Theory.* https://doi.org/10.1080/00131857.2020.1750090.
Peters, M., Jandrić, P., & McLaren, P. (2020b). Viral modernity? Epidemics, infodemics, and the 'bioinformational' paradigm. *Educational Philosophy and Theory*. https://doi.org/10.1080/00131857.2020.1744226.
Philp, J., & Winickoff, D. E. (2018). Realising the circular bioeconomy. OECD science, technology and industry policy papers, no. 60. Paris: OECD. https://doi.org/10.1787/31bb2345-en.

Policy Horizons Canada. (2020). Exploring biodigital convergence: What happens when biology and digital technology merge? Canada: Government of Canada. 11 February. https://horizons.gc.ca/wp-content/uploads/2020/02/Biodigital-Convergence-with-Links-Final-02062020.pdf. Accessed 20 November 2021.

Ravetz, J. (2016). How should we treat science's growing pains? The Guardian, 8 June. https://www.theguardian.com/science/political-science/2016/jun/08/how-should-we-treat-sciences-growing-pains. Accessed 20 November 2021.

Rose, J. (2020). The mortal coil of Covid-19, fake news, and negative epistemic postdigital inculcation. *Postdigital Science and Education, 2*(3), 812–829. https://doi.org/10.1007/s42438-020-00192-7.

Savin-Baden, M. (Ed.). (2021). *Postdigital humans: Transitions, transformations and transcendence*. Cham: Springer.

Shiels, P. G., Kind, A. J., Campbell, K. H. S., Wilmut, I., Waddington, D., Colman, A., & Schnieke, A. E. (1999). Analysis of telomere length in Dolly, a sheep derived by nuclear transfer. *Cloning, 1*(2), 119–125. https://doi.org/10.1089/15204559950020003.

Sutton, R. (2020). Don't blur the line between science and politics: The more scientists breach into politics, the more they risk damaging their credibility. Spiked, 8 October. https://www.spiked-online.com/2020/10/08/dont-blur-the-line-between-science-and-politics/. Accessed 24 November 2021.

Toffler Associates. (2016). Biodigital convergence: The human as critical infrastructure. 21 September. https://www.tofflerassociates.com/vanishing-point/bio-digital-convergence-the-human-as-critical-infrastructure. Accessed 24 October 2021.

U.S. National Library of Medicine. (2018). What are the ethical issues surrounding gene therapy? https://ghr.nlm.nih.gov/primer/therapy/ethics. Accessed 1 October 2021.

Venter, J. C. (2012). What is life? A 21st century perspective. On the 70th anniversary of Schroedinger's lecture at trinity college. The Edge. https://www.edge.org/conversation/j_craig_venter-what-is-life-a-21stcentury-perspective. Accessed 7 October 2021.

Vincent, B., & Loeve, S. (2018). Toward a philosophy of technosciences. In S. Loeve, X. Guchet, & B. Bensaude-Vincent (Eds.), *French philosophy of technology: classical readings and contemporary approaches* (pp. 169–186). https://doi.org/10.1007/978-3-319-89518-5_11.

Warwick, K. (2010). Implications and consequences of robots with biological brains. *Ethics and Information Technology, 12*(3), 223–234. https://doi.org/10.1007/s10676-010-9218-6.

Williamson, B. (2019a). Digital policy sociology: software and science in data-intensive precision education. *Critical Studies in Education, 62*(3), 354–370. https://doi.org/10.1080/17508487.2019.1691030.

Williamson, B. (2019b). Brain data: scanning, scraping and sculpting the plastic learning brain through neurotechnology. *Postdigital Science and Education, 1*(1), 65–86. https://doi.org/10.1007/s42438-018-0008-5.

Wilsdon, J. (2016). *The metric tide: Independent review of the role of metrics in research, assessment and management.* Thousand Oaks: Sage.