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Learning and transforming with Planetary Futures

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Abstract

The data is clear: Global warming is happening. Yet, there is a large gap between how soon we need to end and reverse greenhouse gas emissions and the implementation of transformative innovations at sufficient scale to do so. This chapter proposes we can learn how to increase collective climate action by integrating Planetary Futures produced via data and computation with mind-driven acts of imagination, reflection upon our relationships with others, and attention to meaning-making. It tours some of the recent developments in data availability and advanced computing and presents a selection of already existing data-driven projects which can produce models of Planetary Futures. To encourage learning from these resources, an argument is made for developing the capability called Futures Literacy (cf. Riel Miller) which pertains to the production and use of such models and conceptualizes them as one form, out of many, of a socio-biological phenomena called Anticipation (cf. Robert Rosen). While growing Futures Literacy takes time and patience, a small practical exercise is offered for practicing imagining specific and situated Planetary Futures to reach outcomes such as reflecting upon how people can appreciate novelty. It concludes with reflections upon how utilizing both computationally and non-computationally derived Planetary Futures, we can know more about our current circumstances, our relationships to others, and our sense of why addressing the climate emergency matters.

Introduction

We, the inhabitants of Earth, are living through a climate crisis. In 2023 alone, there was a record number of tropical storms, wildfires, exceptionally hot days, and other phenomena attributable to global warming (Ripple et al. 2023). The possibility and need for an adequate response is widely discussed and climate action is being taken by an increasing variety of actors (IPCC Press Office 2023). Underlying all these conversations and efforts is the larger question of how societies can transform themselves to fully address the multiple dimensions, causes, and impacts of climate change. This chapter offers one pathway toward this needed change: Growing humanity's collective capability to produce, interpret, and discuss Planetary Futures – a form of 'futures literacy' – in processes aimed at learning, meaning-making, and pursuing new ways of being.

Planetary Futures are proposed here as constructs of what living on Earth could be like in a time later than now. They can be produced in a variety of ways for a diversity of purposes, and take many forms such as models, images, scenarios, narratives, simulations, or even indicator systems. They can be general or specific, global or local, and cast onto any time horizon – short or long term. Importantly, very many of these planetary futures are populated with people and other living beings – either older versions of today's inhabitants of Earth or our decedents.

In this essay, the term Planetary Futures refers to kinds of imaginaries which are flowing among us – either inherited from the past or invented in the present. These futures are often generated via anticipation aimed at planning and preparation, but sometimes are also sparked by engagement and struggles to make sense of arising novelty (cf. ‘anticipation for future’ and ‘anticipation for emergence’, e.g., Miller 2018). Generating and conceiving of Planetary Futures entails dancing between global and local scales and detailing general and specific phenomena. In today’s world, as will be elaborated below, a variety of data-driven tools exist for the task. However, this essay argues for the value of combining Planetary Futures built from data with contextually situated imagination informed by our inter-relations and concern for others.

A plausible Planetary Future motivates this chapter’s core idea: Within the next 5-10 years, climate impacts will culminate to such an extreme that all businesses, governments, and populations – even the most fossil fuel dependent ones – will be highly motivated to address climate change at sufficient scale to transform how humans utilize resources and relate to our ecosystems (cf. Berzonsky and Moser 2017). However, to effectively change ‘how things work’ so humanity can fully adapt, mitigate, or otherwise respond to the massive transformations driven by Earth and humanity’s intrinsically entangled and complex journey of ‘becoming’, we will need more than our plausible Planetary Futures built from data (Wright 2014). We will also need the capability to expand, vary, and diversify the kinds of Planetary Futures in use – adding the ‘appreciation of novelty’ to the more common ‘planning and preparation’ (cf. Miller 2018)– as well as an increased capacity and willingness to collectively contextualize, discuss, and make sense of the lively embers of potential change in the present.

Planetary Futures

For as long as humans have been able to conjure them, futures have been imagined for various purposes based on evidence found in the environment and collective memory. Some of these futures have had profound effects on how, over time, humans built social patterns as well as dynamics for relating to each other, to the rest of Earth’s life, and to the many habitats and landscapes found on our common home: Earth.

The very earliest humans, in a plausible past, did not have the concept of planet or know that they lived on one. Ancient astronomers started to raise attention to this idea. In the recent past, the convergence of several tools and conceptual leaps have made it common knowledge that we all live on a relatively small and unique planet called Earth. In the 20th century, we have taken many photos of our home¹ from Low Earth Orbit², the Moon (NASA n.d.), or from distant planets in our solar system (NASA 2023). Images and reflections on ‘one small step’ and ‘a pale blue dot’ have offered pause and reflection about the preciousness of this locality in the vastness of space. Today, general knowledge about Earth is integrated in education systems and popular culture. Furthermore, media and cultural exchange allow for a sense of connection and common cause across distances. In the first decade of our current century, a combination of remote sensing (e.g., through satellites), Internet communication technologies, and big data have given billions of people instantaneous access to detailed information about any place, at any scale, via devices they carry regularly on their person. This contemporary setting offers several commonplace sources of what can be called a *planetary awareness* – a precursor ingredient to conjuring Planetary Futures.

¹ For a timeline, see https://en.wikipedia.org/wiki/Timeline_of_first_images_of_Earth_from_space, accessed 21.11.2023.

² See Earth tab of International Space Station Galleries on <https://www.nasa.gov/international-space-station/space-station-gallery/>, accessed 21.11.2023.

Today, many billions of humans frequently use computing devices. We³ could be called *Homo sapiens computare* (cf. *Homo sapiens faber, etc.*). For this large population of our species, computation capacity is closely coupled to cognition and perception. In other words, what *Homo sapiens computare* think, see, and do are mediated by their computational tools. Due to the extensiveness of computation in society, even those people and other living beings who never use computational augmentation themselves are inhabiting built environments, infrastructures, and mobility systems designed via computation, represented in computational systems, and monitored by others via computational systems. It could even be argued that computation – with all its required electromagnetic signaling (e.g., WiFi, satellite beams, cellphone coverage areas) – is becoming part of the ‘affordance landscape’ (Walsh 2014) for all of Earth’s life. Speculatively, these computational affordances may have already co-constituted new repertoires of goals for both human and non-human life systems.

Among humans, the rise of *Homo sapiens computare* corresponds to a rising emphasis upon ‘computable data’ as the core input needed to build compelling models of reality, including tools for comprehending the present state of various phenomena and systematically imagining its extension backward and forwards through time. These simulations of past and future can be generated in increasingly sophisticated ways thanks to many converging advancements. One area of development is the increasing quantity of computable data which is now vast and varied – pertaining to many aspects of our world including its physical planetary dynamics, habitats and ecosystems, human activities, individual beings, and more. Another angle of advancement is our increasing compute power combined with the invention of entirely new kinds of computation.

Today, the increasing volume and variety of computable data is met with more extensive and diverse computing power. Machine Learning (ML) and Artificial Intelligence (AI) have enjoyed sustained attention over the past decades, and today there exist several projects, services and products ‘blowing our minds’ with their potential uses. Meanwhile, the race to build supercomputers continues – the fastest for 2023 being Frontier in the U.S. (1,194.00 TFlop/s), Fugaku in Japan (442 TFlop/s), and LUMI in Finland (309.1 TFlop/s) (TOP500 2023). Quantum Computing has also enjoyed sustained attention and at present many such machines are built, functional, and available via Cloud-based service models to researchers and developers (Dargan 2022). Beyond these well-known computing trajectories, innovators are identifying ways to utilize photonics in device hardware, developing approaches to using DNA molecules for data storage (Rawat 2023), and growing neurons to perform basic computational tasks (Ghosh 2022). On top of these developments, computer engineers have speculatively proposed a next phase in computing – to follow conventional and quantum – which is initially being called Thermodynamic Computing and would be inspired by how ‘life computes’ (Hylton, Conte, and Hill 2021). These advances are pushing the limits of we presently know as computing and spark novel ideas for the kinds of approaches to simulating Planetary Futures that can be produced and shared in the coming years.

Advanced computation is even being applied to help us situate our planet in the unfolding story of the cosmos. For example, a simulation called Uchuu plots the structural evolution of a cube of our universe, 9.63 billion light years per side. This simulated cube of the universe contains 2.1 trillion astronomical objects at the granularity level of a galaxy. It took a team of international researchers and one Earth year and 20 million compute-hours of the supercomputer ATERUI II to produce. It enables exploration of the evolution of the structure of the universe from the the Big Bang to now, including a plausible distribution of dark matter. (NAOJ 2023). This kind of application of advanced computing to model helps locate our existence in a larger story of cosmological transformation, another useful ingredient for producing Planetary Futures.

³ I typed this chapter on a computer, and you might be reading it on one.

The Uchuu example is impressive. Yet, arguably, people were able to build planetary models or contemplate our place in the cosmos long before our less-than-one-century-old computational era. Humans were able to predict seasons, invent calendaring systems and notice changes in heavens. However, computation has opened new approaches which can widen human perception and lead to new realizations. Based on data – recorded observations of phenomena – we can imagine plausible futures under the pattern of ‘based on X past evidence, we assume Y could happen’ in a systematic and robust manner.

Examples of computationally derived Planetary Futures

There is no need to wait for future times to consider some remarkable examples of Planetary Futures produced from computable data. The following list gives a taste of the practical purposes to which they can be applied.

- **Neo-Carbon Energy**
For these scenarios, energy systems were modeled and simulated by a research team at Lappeenranta University (Finland) for every major region of the world at a resolution of 30-minute time increments between 2015 and 2050. The simulation allowed the researchers to make a cost comparison between various energy-source mixes under a detailed set of assumptions. They found that in all scenarios, Nuclear and Fossil Fuel energy systems were the most expensive options while renewable energy systems were the least.⁴
- **Quantitative CoVID-19 scenarios**
Various groups around the world produced COVID-19 scenarios during the COVID-19 pandemic. Notably, a research team at Washington University (St. Louis, Missouri, U.S.) produced and frequently updated a set of quantitative scenarios for nearly all nations in the world. These scenarios projected quantities of new cases, hospitalizations, and COVID-19 deaths under various action scenarios (e.g., 80% wearing masks or 90% vaccinated). The typology of scenarios was regularly updated to reflect latest available health policy recommendations.⁵
- **IPCC Climate Models** – Climate Scientists have built dozens of simulations based on historic weather data and an ever-improving understanding of Earth systems to project how Climate Change may unfold. The data upon which these climate change simulations are built are becoming increasingly comprehensive in terms of spatial and temporal detail and variety of systems modeled. Several research teams around the world build these models which are used to inform IPCC reports. The year 2100 has been a common time horizon used across several of these models for the purpose of comparison. (Climate Atlas 2023). A recent study showed that the past projections from these models are highly credible (Buis 2020).
- **Big Data for Biodiversity** – While it’s common to discuss threatened or extinct species, the practice of counting populations of unique species is a key challenge in biology. Doing so often takes multiple modes of data collection, various spatial and temporal scales, and data-relevant forms of approximation. In one example, combining data from the citizen science app eBird with biologist field observations, researchers made an algorithm that estimated populations of 9700 bird species to form a first-of-its kind ‘bird census’ (Cox 2021). In

⁴ See <https://neocarbonenergy.fi>, Internet of Energy, accessed 6 September 2023.

⁵ <https://covid19.healthdata.org/> (accessed 21.11.2023) paused its activities in December 2022.

another, space-based monitoring tools and data interfaces alert humans when another species is in danger (“Biodiversity ” n.d.). Yet another example is a research project at University of Helsinki which is developing and demonstrating biodiversity monitoring systems and data gathering standards (Lifeplan Project n.d.). Some researchers even propose the creation of an ‘internet of animals’ in which very many individual living beings are actively tracked (Larson 2021).

- **Digital Twin Earth** – Digital Twins are often discussed as enablers of more efficient manufacturing or governance. Digital Twins are computational models of actual entities – such as a factory assembly line, a building, a city, or even a person – which are continually updated with live data. The Digital Twin Earth project, supported by European Space Agency and others, aims to create a similarly always-being-updated model of Earth and its many systems. Due to a variety of terrestrial and space-based remote sensing systems, many believe such a system can be created. Such a system would show real-time developments of climate change phenomena and build increasingly detailed projections at local and global scales. (Rao et al. 2023; Voosen 2020)

All computer simulations used for modeling reality or exploring scenarios—like the above examples for energy systems, CoVID-19 cases, climate change, biodiversity, and digital Twin Earth—provide a basis for describing Planetary Futures, allowing people to connect potential local actions to global effects. In other words, they can drive perception of what is happening now and what could transform in the future.

Models and simulations like these are built from computable data translated into projections via algorithms. As beautifully concise as their numerical outputs are, these futures – like all others – are based upon assumptions about how various phenomenological processes interrelate. High-quality simulations are transparent about these assumptions (e.g., Neo-Carbon Energy, the IPCC ensemble) so they can be subjected to scientific scrutiny and refined. In future, there could be simulations of Planetary Futures based on assumptions which are unreadable by humans due to the computing approach used to produce them.

Data-driven approaches to imagining Planetary Futures merit close attention because they serve as an evidence-driven basis for discussing present circumstances and potential transformations. Obviously, they are fueled by data from the past – even in the case of Digital Twins where ‘real-time’ data (e.g., from microseconds in the past) is fed into the process. Because the future is, by definition, unknowable in advance, reliance on data from the past places a limit on what these systems can tell us about future changes. For example, relying on past data limits the extent and kind of novelty can be produced – while truly transformational innovations will require new realizations about what can change and relevant ideas for action. We will likely need more than well-constructed programs and computational power to produce the kinds of insights about the future which are useful for reconfiguring how we relate to each other, the rest of Earth’s life, and our common home.

Computationally produced Planetary Futures concerning climate change, energy systems, and biodiversity have contributed significantly to growing a collective awareness of significant issues, their potential impacts, and the need for action. However, this category of Planetary Futures has yet to inspire an adequately scaled, multi-level, coordinated, and impactful collective human response. Per the thesis of this essay, a new collective capability is needed to close this motivation gap – the capability to invent and describe Planetary Futures, discuss them, interpret and explore their meanings, identify potential transformation, and innovate new ways of being together on Earth. Engaging in the development of such a capability offers pathways for augmenting the utilization of

computationally generated Planetary Futures. These augmentations could catalyze much-needed transformational action.

Growing our capabilities to invent Planetary Futures and inspire transformational action

‘Futures Literacy’ is proposed as the capability to diversify, expand, and vary how and why we build imaginary futures and apply them (cf. Miller 2018; Conway 2023). Understanding how Futures Literacy can be developed and applied is undertaken by a same-named program of the UNESCO Social & Human Sciences Sector and a network of more than 40 UNESCO Chairs around the world. Futures Literacy is a capability for engaging with the diverse ways life builds, engages, and utilizes models of the future (Louie 2010; Rosen 1999). Humans, as a social species, frequently engage in Anticipation together –inventing, exchanging, and inventing models of the future as needed to pursue goals.

Planetary Futures produced from computation and computable data give us increasing clarity on what has happened up to now and plausible ways things could develop in the future. Futures Literacy contextualizes approaches to engaging with the future as forms of Anticipation. It introduces the notion that there are other forms of Anticipation which could also be deployed. Seeking to grow Futures Literacy in relation to Planetary Futures does not aim to replace computational approaches to foresight, but to include – and ensure non-exclusion of—additional modes of engaging in a wider variety of Anticipation, including via non-computational means.

Learning Futures Literacy can be uncomfortable. Most who begin developing it must locate its ideas with concepts and paradigms they are already familiar – a normal part of any learning journey. In a famous museum, large text informs visitors that (paraphrased) ‘to create the future, you must first imagine it’. This is a commonly expressed idea and reflects a common form of Anticipation among people living in industrialized societies. The underlying ‘how and why’ of this idea is ‘preparing and planning’ – and follows the form of building models of the future for the purpose of formulating actions toward the future (cf. ‘Anticipation for Future’, Miller 2018). One of the key ideas in Futures Literacy which is most difficult to grasp is the idea that you can engage in Anticipation that is not about preparation or planning at all.

People who are growing their Futures Literacy take interest in also using this other form of Anticipation – so called ‘Anticipation for Emergence’ (cf., Miller 2018). This form of Anticipation is about noticing and appreciating the novelty arising from our complex and transforming world. It is about struggling to see and interpret new phenomena, new ideas, or invent new words to describe something yet-to-exist. It is about being able to do this noticing, appreciating, and struggling while withholding from ‘solving mind’. It feels like improvising along with ‘the becomingness’ of our world.

Growing Futures Literacy is about toggling between these two kinds of Anticipation – to be able to build and apply models of the future for preparation and planning, while also leaving room for appreciating novelty. Experiences and exercises – big and small – can help a group develop Futures Literacy. A well-established, efficient, and effective learning experience is a Futures Literacy Lab. Smaller exercises are also possible, such as experimental check-ins at meetings (Balcom Raleigh and Richards 2022). In the following section, a simple exercise which was invented at the Desirable Futures 6 event is offered to support such learning.

A small Futures Literacy exercise to support learning from Planetary Futures

Before reading the exercise in Box 1, it will be helpful to know its purpose (Why) and method (How).

In the field of Information Science, there are continuing discussions about the differences between data, information, and knowledge. A common delineation is that Data can be compiled into information, and Information can be built up into knowledge, and Knowledge can support the development of wisdom. (Zins 2007.) However, quantum physicists and cosmologists raise the idea that our whole universe is made of something like information – from quantum to the interstellar scales (cf., measurement as ‘causal intra-actions’, Barad 2007 p. 337). These notions imply that computable data can only deliver us a fraction of rich information involved in our existence (cf. Lanier 2011). An interpretation of these ideas is that the universe is filled with what can be called – in search of a better word – some kind of ‘pre-data’. Applying this interpretation, when people use instruments like a powerful space-based telescope or research questionnaire to detect some phenomena, the target is imbued with this ‘pre-data’ that when mediated by the instrument becomes encoded as data. Accessing the rich terrain of this ‘pre-data’ can be a pathway to new realizations. Accessing this ‘pre-data’ is the Why of this exercise.

To accomplish this exercise, imagination and reflective thinking will be used. Your mind is filled with pre-data. It can be accessed without computation, allowing for the exploration of one’s own intersubjective awareness of being alive, situated relationships to others, and own hopes, fears and other emotions related to the prospect of living in a transformed world. A non-computational process like this generates inter-personally meaningful futures. This is the ‘How’ of the exercise, presented in Box 1.

Box 1. Exercise – Situating Planetary Futures

1. Find a partner (or, do now and share with someone else later).
2. Quietly reflect. Imagine a child you know who is 10 years old or younger.
3. Add 35 years to their age. Imagine this child has grown into a middle-aged adult.
4. Reflect on how climate change is in this future: Is Earth hotter? Has society radically transformed itself and addressed it in time? Something else?
5. Imagining this future, answer this question:
What does this person you know do on a regular basis to encounter and appreciate novelty?
6. When you and your partner are finished – share what you imagined with each other.

After trying this exercise, you will have produced a contextually unique Planetary Future, populated with someone you know doing something interesting, maybe even novel. This exercise can enable many kinds of images, thoughts, and feelings. Two intended outcomes are, first, to de-generalize the future and situate it within the context of one’s own relationships and life experiences; and second, to entangle subjective knowledge and perception with ideas inspired indirectly by more general data-driven models of the future.

The question in Step 5 of this exercise serves as a reminder: Novelty happens and will continue to happen in the future. By imagining how a person in the future encounters ‘the new’ and the approach they take to include it in the enrichment of their life experiences, it is possible to invent some practice for appreciating novelty which could plausibly be developed in the present. It raises productive questions how Anticipation for Emergence given more attention: What practices of appreciating novelty can be adapted by individuals and collectives? How could children and youth invent their own practices? How can we participate in ‘becoming with’ ongoing transformations

while passing forward something useful to the rising generation? Inquiring into these kinds of reflective questions after doing this exercise supports learning from Planetary Futures.

Conclusions

While we cannot know the future, computable data and advances in computer modeling and simulation have made it possible for us to have better understanding and awareness of our current circumstances and their plausible potential developments. These computer-driven planetary futures contribute significantly to the case for climate action but are necessarily built from evidence from the past and are limited in how they can help us appreciate novelty. By combining computable data with other sources for imagining futures, we can expand our perception of transformation and close the motivation gap for addressing Climate Change. Growing societal Futures Literacy and a general-level interest and willingness to utilize intersubjective and relational inputs while imagining futures can help us invent and share Planetary Futures useful for learning and transforming. Combining awareness of the outcomes computationally driven models of Planetary Futures and being inspired by our own relationships and sense of being – we can motivate much needed transformative innovation aimed at the collective survival of all of Earth’s Life.

About the Author

Nicolas Balcom Raleigh researches how innovators who are addressing the climate emergency can develop and benefit from capabilities to expand, diversify, and vary modes and purposes for imaging futures (‘Futures Literacy’). His approach emphasizes co-inquiry informed by an appreciation for complexity, unknowability, emergent novelty, and insightful value-creation for participants. He is UNESCO Co-Chair of Learning for Transformation and Planetary Futures (2020-2028) and doctoral researcher at University of Turku (Finland); and president of Foresight Europe Network (2023-2024).

References

- Balcom Raleigh, Nicolas, and Martyn Richards. 2022. “12 Tasty Futures Literacy Recipes for Sustainability Innovators*.” Unesco Chair in Learning for Transformation and Planetary Futures. March 15, 2022. <https://unescochair.utu.fi/12-tasty-futures-literacy-recipes-for-sustainability-innovators/>.
- Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Second Printing. Durham: Duke University Press Books.
- Berzonsky, Carol L., and Susanne C. Moser. 2017. “Becoming Homo Sapiens Sapiens: Mapping the Psycho-Cultural Transformation in the Anthropocene.” *Anthropocene* 20 (December): 15–23. <https://doi.org/10.1016/j.ancene.2017.11.002>.
- “Biodiversity .” n.d. Copernicus Climate Change Service. Accessed November 20, 2023. <https://climate.copernicus.eu/biodiversity>.
- Buis, Alan. 2020. “Study Confirms Climate Models Are Getting Future Warming Projections Right.” NASA Global Climate Change. January 9, 2020. <https://climate.nasa.gov/news/2943/study-confirms-climate-models-are-getting-future-warming-projections-right/>.
- Climate Atlas. 2023. “Climate Change Projections: How Computer Models Help Us Understand Climate .” Climate Atlas of Canada. 2023. <https://climateatlas.ca/climate-change-projections>.
- Conway, Maree. 2023. “EP 170: FuturePod Conversations - Riel Miller and Maree Conway.” FuturePod. October 23, 2023. <https://www.futurepod.org/podcast/ep-170>.
- Cox, Lisa. 2021. “World Is Home to 50bn Birds, ‘Breakthrough’ Citizen Science Research Estimates.” *The Guardian*, May 17, 2021. <https://www.theguardian.com/environment/2021/may/18/world-is-home-to-50bn-birds-breakthrough-citizen-science-research-estimates>.

- Dargan, James. 2022. "13 Quantum Cloud Computing Software Companies in 2022." May 3, 2022. <https://thequantuminsider.com/2022/05/03/13-companies-offering-quantum-cloud-computing-services-in-2022/>.
- Ghosh, Pallab. 2022. "Lab-Grown Brain Cells Play Video Game Pong." *BBC*, October 12, 2022. <https://www.bbc.com/news/science-environment-63195653>.
- Hylton, Todd, Thomas M. Conte, and Mark D. Hill. 2021. "A Vision to Compute like Nature." *Communications of the ACM* 64 (6): 35–38. <https://doi.org/10.1145/3431282>.
- IPCC Press Office. 2023. "Urgent Climate Action Can Secure a Liveable Future for All." IPCC. March 20, 2023. <https://www.ipcc.ch/2023/03/20/press-release-ar6-synthesis-report/>.
- Lanier, Jaron. 2011. *You Are Not a Gadget: A Manifesto*. Reprint. New York: Vintage.
- Larson, Christina. 2021. "Scientists Hail Golden Age to Trace Bird Migration with Tech." *AP News*, June 10, 2021. <https://apnews.com/article/business-birds-technology-science-environment-and-nature-03234b4ba5506dae02e6dcd16e3c33de>.
- Lifepan Project. n.d. "Lifepan: A Planetary Inventory of Life." University of Helsinki. Accessed November 20, 2023. <https://www.helsinki.fi/en/projects/lifepan>.
- Louie, A H. 2010. "Robert Rosen's Anticipatory Systems." *Foresight (Los Angeles, Calif.)* 12 (3): 18–29. <https://doi.org/10.1108/14636681011049848>.
- Miller, Riel. 2018. "Sensing and Making-Sense of Futures Literacy: Towards a Futures Literacy Framework." In *Transforming the Future: Anticipation in the 21st Century*, edited by Riel Miller, 1st ed., 15–36. London: Routledge.
- NAOJ. 2023. "Largest Virtual Universe Free for Anyone to Explore." NAOJ: National Astronomical Observatory of Japan. November 21, 2023. <https://www.nao.ac.jp/en/news/science/2021/20210910-cfca.html>.
- NASA. n.d. "Apollo 8." NASA Science. Accessed November 21, 2023. <https://www.nasa.gov/mission/apollo-8/>.
- . 2023. "Voyager 1's Pale Blue Dot." NASA Science. September 4, 2023. <https://science.nasa.gov/resource/voyager-1s-pale-blue-dot/>.
- Rao, Yuhan, Rob Redmon, Kirstine Dale, Sue E. Haupt, Aaron Hopkinson, Ann Bostrom, Sid Boukabara, et al. 2023. "Developing Digital Twins for Earth Systems: Purpose, Requisites, and Benefits." *ArXiv*. <https://doi.org/10.48550/arxiv.2306.11175>.
- Rawat, Sachin. 2023. "Is DNA Data Storage Ready for Data Centers?" SynBioBeta. November 7, 2023. <https://www.synbiobeta.com/read/is-dna-data-storage-ready-for-data-centers>.
- Ripple, William J, Christopher Wolf, Jillian W Gregg, Johan Rockström, Thomas M Newsome, Beverly E Law, Luiz Marques, et al. 2023. "The 2023 State of the Climate Report: Entering Uncharted Territory." *Bioscience*, October. <https://doi.org/10.1093/biosci/biad080>.
- Rosen, Robert. 1999. *Essays on Life Itself*. New York: Columbia University Press.
- TOP500. 2023. "Highlights - June 2023: 61st Edition of the TOP500 ." Top 500. June 2023. <https://www.top500.org/lists/top500/2023/06/highs/>.
- Voosen, Paul. 2020. "Europe Builds 'digital Twin' of Earth to Hone Climate Forecasts." *Science* 370 (6512): 16–17. <https://doi.org/10.1126/science.370.6512.16>.
- Walsh, Denis M. 2014. "The Affordance Landscape: The Spatial Metaphors of Evolution." In *Entangled Life*, edited by Gillian Barker, Eric Desjardins, and Trevor Pearce, 4:213–36. History, Philosophy and Theory of the Life Sciences. Dordrecht: Springer Netherlands.
- Wright, Kate. 2014. "Becoming With: Living Lexicon for the Environmental Humanities." *Environmental Humanities* 5: 277–81.
- Zins, Chaim. 2007. "Conceptual Approaches for Defining Data, Information, and Knowledge." *Journal of the American Society for Information Science and Technology* 58 (4): 479–93. <https://doi.org/10.1002/asi.20508>.