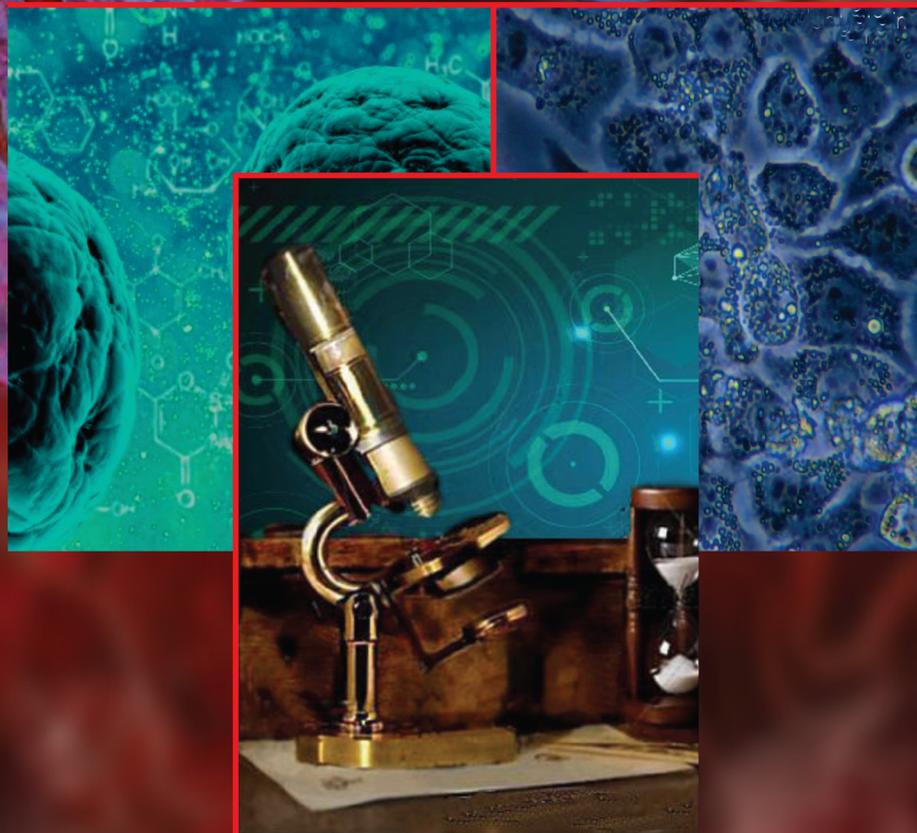


# Cognition-Based Evolution

*Natural Cellular Engineering and the Intelligent Cell*

**William B. Miller, Jr.**



**CRC Press**  
Taylor & Francis Group

A SCIENCE PUBLISHERS BOOK

# Cognition-Based Evolution

## Natural Cellular Engineering and the Intelligent Cell

**William B. Miller, Jr.**

Banner Health Systems  
Bioverse Foundation  
Paradise Valley, Arizona  
USA



**CRC Press**

Taylor & Francis Group  
Boca Raton London New York

---

CRC Press is an imprint of the  
Taylor & Francis Group, an **informa** business  
A SCIENCE PUBLISHERS BOOK

Cover credit:

**Background image** – Image taken from Pixabay License.

**Top left image** – Image taken from Pixabay License and modified by the author.

**Top right image** – Image taken from Wiki commons. The file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Attribution: User:SubtleGuest

**Top centre image** – Top background from Freepik.com. Bottom foreground content by author, William B. Miller, Jr.

First edition published 2023

by CRC Press

6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742

and by CRC Press

4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

© 2023 William B. Miller, Jr.

*CRC Press is an imprint of Taylor & Francis Group, LLC*

Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, access [www.copyright.com](http://www.copyright.com) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. For works that are not available on CCC please contact [mpkbookspermissions@tandf.co.uk](mailto:mpkbookspermissions@tandf.co.uk)

*Trademark notice:* Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

*Library of Congress Cataloging-in-Publication Data (applied for)*

ISBN: 978-1-032-26147-8 (hbk)

ISBN: 978-1-032-26148-5 (pbk)

ISBN: 978-1-003-28676-9 (ebk)

DOI: 10.1201/9781003286769

Typeset in Times New Roman  
by Radiant Productions

# Dedication

---

---

*To  
Linda, Lauren, and Scott*



# Taylor & Francis

Taylor & Francis Group

<http://taylorandfrancis.com>

# Preface

---

---

A major point of emphasis in this book is that our intelligent cells utilize chance events to channel creativity. Chance entered my life through an unanticipated encounter with a ‘boy named Sue’ on a blustery fall day 15 years ago. ‘Sue’ was the towering Tyrannosaurus Rex fossilized skeleton that dominates the magnificent rotunda of the Chicago Field Museum. I had visited the museum one late afternoon seeking relaxation after many days of intensive medical meetings. There was no purpose other than a pleasant diversion. Before that moment, my interest in evolution had been superficial. Yet, one glimpse of that titanic creature changed everything. Despite obvious differences in scale, I was startled by unanticipated resemblances between the major bones of the T. Rex and our human ones. My companion that afternoon was an astute physician and colleague who had joined me on this brief excursion. When I expressed my amazement at these anatomic similarities and my further impression that the conventional evolutionary narrative seemed critically lacking, his rejoinder was adamant. I was failing to properly appreciate geological time-spans. It was fanciful to think otherwise. For reasons that still elude me, a gauntlet had been thrown.

My broad medical training as a physician was a singular advantage. I was already struggling to reconcile the patterns of infectious disease that could be observed in my daily medical practice with the then governing perspectives of microbial life that existed several decades back. To my appraisal, their consistent patterns of behavior suggested preferences for specific body locations. If that was the case, they likely had a degree of sensory awareness and intelligence. That thought sparked a preliminary investigation of the intricacies of the microbiome and, rather unexpectedly, led to a second career as an evolutionary biologist focusing on this novel perspective.

In all endeavors, it is always a matter of timing, perseverance, a modicum of innate abilities, and luck. Each of these ingredients contributes to the innumerable connections necessary to succeed in any complex endeavor. Some of these fortuitous relationships merit special mention. Foremost among these was the early endorsement of my unconventional thoughts by my brilliant, now-deceased brother-in-law, Spencer W. Franck, Jr. He discerned a kernel of merit in my arguments when so many others were dismissive. Without his encouragement at a pivotal moment, my efforts would have dwindled, and this volume would never have been written.

I was also blessed to meet a remarkable biologist, John Torday, who became my early invaluable collaborator. The opportunities to exchange ideas and debate his unconventional insights were indispensable to all contained herein. My additional scientific collaborators over the last several years also claim my particular thanks:

Frantisek Baluška, Arthur Reber, Jean Guex, Francisco Enguita, Ana Lúcia Leitão, and Perry Marshall. Although not direct collaborators, a few other scientists deserve personal note due to their overarching influence: Denis Noble, Frank Ryan, Luis Villarreal, Arnold De Loof, Brian J. Ford, James Shapiro, John Lieff, Michael Levin, Chris Fields, Eugene Koonin, Guenther Witzany, Pamela Lyon, Pedro Marijuán, Jaime Cárdenas-García, Loris Zamai, Richard Jacobs, and Tam Hunt. However, it must be emphasized that this book could never have materialized without the hundreds of exceptional scientists cited in this volume. Isaac Newton stated it best in a letter to Robert Hooke in 1675: “If I have seen further it is by standing on the shoulders of Giants”. My hope is that this volume will burnish their remarkable achievements and serve as a stepping stone to the next better truth.

These acknowledgments would be woefully incomplete without emphasizing the paramount relationship that sustained this whole enterprise and whose value I regard as immeasurable. None of this would have been possible absent the steadfast and loving support of my inestimable wife, Linda.

Finally, my special thanks goes to Taylor and Francis/CRC Press. Their foresight enables this first volume specifically devoted to Cognition-Based Evolution.

# Contents

---

---

<i>Dedication</i>	iii
<i>Preface</i>	v
1. Introduction: Evolution Recast	1
2. Neodarwinism: Evolution in the 20th Century	12
3. 21st Century Evolution: The Intelligent Measuring Cell	22
4. The Cellular Information Cycle and Biological Information Management	35
5. The Senome: The Cellular Connection with Environmental Information	47
6. The N-space Episenome: Concordant Cellular Information	58
7. Natural Cellular Engineering as Multicellular Problem-solving	72
8. Non-random Variations in Natural Cellular Engineering	84
9. The Virome and Natural Viral-Cellular Engineering	98
10. Holobionts: A Consensual ‘We’	109
11. The Role of the Microbiome in the Evolution and Development of Holobionts	120
12. Four Domains and the Primacy of the Unicellular State	136
13. Speciation	147
14. Sexual Reproduction and its Impact on Evolutionary Variation	163
15. Extinction	171
16. Old Controversies Revisited—Where is the Cusp of Creativity?	182
17. The Primacy of Cellular Consciousness	196
18. How Might Biology Instruct Physics?	209
19. A Separation from the Past	222
20. Conclusion—The Intelligent Measuring Cell	232
21. Appendix: Differential Features Between Cognition-Based Evolution and the Neodarwinian Modern Synthesis	241
<i>Index</i>	247



# Taylor & Francis

Taylor & Francis Group

<http://taylorandfrancis.com>

## CHAPTER I

# Introduction Evolution Recast

---

---

*“Sooner or later you must move down an unknown road that leads beyond the range of the imagination, and the only certainty is that the trip has to be made”.*

Bruce Catton, historian (1899–1978)

In a celebrated 1973 essay, the renowned evolutionary biologist Theodosius Dobzhansky famously exclaimed: “Nothing in biology makes sense except in the light of evolution” (Dobzhansky 2013). Generations of biologists have co-opted this striking phrase in defense of Darwinian evolution by natural selection. The maxim still holds, but decades later, it is now found to be incomplete. Based on definitive research, an illuminating amendment is mandated: “Nothing in biology and evolution makes sense except in the light of cognition”.

Scientific investigations warrant that all cells are intelligent at their scale (Ford 2004, 2009, 2017, Lyon 2015, Miller 2016a, Majumdar and Pal 2017, Reber 2019). Consequently, biological and evolutionary development have been upended. Cognition-Based Evolution inaugurates from within this secure, unorthodox base, firmly placing all biology and evolution within a framework of ‘the intelligent measuring cell.’ (Miller 2016a, 2018, Baluška and Miller 2018, Miller et al. 2019, Torday and Miller 2020, Miller et al. 2020a, Baluška et al. 2021). From this fresh vantage, a contemporary, encompassing evolutionary narrative unfolds that overcomes the accumulating manifest deficiencies within conventional Neodarwinian evolutionary theory.

The initial premises of evolution theory had many forebears but commenced decidedly with the publication of Darwin’s seminal, ‘On the Origin of Species’ in 1859 (Darwin, 2004 [1859]). It was greeted by an immediate onslaught of insistent countervailing attacks on both religious and scientific grounds. Nevertheless, its principle tenets have achieved undeniable primacy, reaching such an extent that Darwinism and evolution are viewed as an identity by the majority of the scientific community and the general public. Any casual web search on evolution populates

with nearly limitless sources insisting on the hallmark principles of the modern interpretation of Darwinism: evolution is caused by natural selection acting on random genetic variations that express as gene frequencies in populations. Over decades, natural selection took center stage in our evolutionary narrative. Although there is no question that natural selection plays a significant role in evolutionary development, the 20th century emphasis on that process as a driving force obscured that its consequences must always be post-facto to preceding variations. Consequently, a predominant interpretation of the scope of natural selection has emerged that significantly misinterprets its role. As will be explored, a more productive evolutionary focus centers on the exact manner in which biological variations arise to yield sustainable heritable products. Cognition-Based Evolution (CBE) endorses a robust alternative to the conventional Neodarwinian narrative of random genetic variations. Multicellular evolutionary variation emerges from the collective problem-solving actions of intelligent, measuring cells.

Ironically, Darwin's success has become its inadvertent reciprocal limitation. The beguiling elegance of his theory of natural selection forcefully gripped the imaginations of scientists and the general public with uncommon facility. Its popular reduction to 'survival of the fittest' swiftly became its implicit embodiment. Yet, placing the theory of evolution by natural selection in those terms was a disservice to the meticulous depth of Darwin's thoughts.

Part of its enduring primacy is that once this alluring theory is considered, it seems intuitively obvious. Thomas Henry Huxley (1825–1895), a prominent English biologist and contemporary admirer of Darwin, examined natural selection theory and despondently stated: "How extremely stupid not to have thought of that" (Huxley 1887). Yet, the concept of natural selection was not novel to Darwin. Nor is it the reason that he deserves his place among the pantheon of preeminent scientific intellects. The sharp point of Darwin's brilliance was his deductive observation that creatures inevitably varied over time and in so doing, propelled evolutionary changes. He had no idea how those variations occurred, but he knew that biological flexibility was a consistent product of breeding in animal husbandry and agriculture. He termed these variations 'sports', adopting the common terminology of breeders. With singular insight, he concluded that these variations represented the feedstock of continuous evolutionary change from a common progenitor forward (Miller 2013). He also intuited a further crucial, incumbent linkage. The persistence of these variations depended on their reproductive success as a function of natural selection. In a flash of insight, Darwin was the first to fully grasp the correct biological hierarchy. Variations occur first; selective influences follow. Cognition-Based Evolution (CBE) distinguishes itself from conventional Neodarwinism precisely on these grounds by concentrating on the sources of variation rather than the influence of selection.

Unquestionably, the Darwinian theory of evolution by natural selection has undergone its own form of adaptive evolution for over 100 years. There have been persistent attempts to refresh it by incorporating fresh scientific discoveries, such as the rapidly expanding science of genetics. Consequently, its current embodiment is represented by contemporary Neodarwinism, epitomized as the Modern Synthesis and serving as the current mainstay of evolutionary thought. This modern iteration of Darwinism rests on four cardinal buttresses: a) evolution is due to predominantly

random heritable genetic variations, b) the persistence of these variations relates to reproductive success subject to natural selection, c) longitudinal descent through these successive random variations is necessarily gradual, and d) the target of selective influence is primarily centered at the level of the visible macroorganic form (Futuyma 2017, Koonin 2012).

Cognition-Based Evolution (CBE) stands apart from each of these particulars. Most significantly, this entirely different evolutionary explanation inaugurates from a unorthodox base compared to Neodarwinism. All cells are intelligent, and further, that intelligence defines the living state and all subsequent evolutionary development. Beginning from this unprecedented source, CBE proceeds in an entirely distinct manner from Neodarwinism: variations and their deployment as adaptations are the result of intelligent cells collectively assessing and communicating information to problem-solve. This collaborative process is a form of natural engineering, and it is this self-organizing impulse that directly drives multicellularity. Significantly, this constructive co-engineering process requires the co-participation of the three cellular domains (Prokaryota, Archaea, Eukaryota) and the virome. By this means, CBE methodically explains why all multicellular eukaryotes are obligate holobionts comprised by participants from all of the elemental domains. Multicellular eukaryotes are the unicellular domains' means of continuously exploring and adapting to environmental cues, thereby permitting their permanent planetary perpetuation.

Although not generally recognized, biology has remained an orphan among its brethren sciences. It alone had not uncovered a method of becoming a field of exacting measurement rather than observation. Undoubtedly, sophisticated statistical analysis is applied to population genetics, but it has added less than hoped since it offers no predictive value. While other fields were transforming in the last several decades, especially physics, evolutionary biology remains a largely descriptive enterprise (Moss 2012, Nicholson 2012).

Decades ago, initial genetic discoveries gave tantalizing hope that fundamental causations might be revealed through its deeper scrutiny. Yet, fifty years later, evolutionary biology remained mired in post-facto associations and presumptive correlations. Although our technical abilities to understand genomic patterns have grown explosively, these have yielded no breakthroughs for the 'why' of what we can observe. The genetic building blocks that underpin all living things are being scrupulously identified, but why they are arranged precisely as they are remains as elusive now as decades ago. Biology's principle handicap has been that other than its faith in natural selection, the exact mechanisms that determine biological or evolutionary development have not been illuminated (Scheiner 2010). Despite much research, a coherent central theory of biology beyond Neodarwinian assumptions remained lacking (Torday 2015). Consequently, the long-term major questions about evolution are still currently addressed through compartmentalized theories developed within siloed disciplines (Schreiner 2010).

For example, the issue of the persistence of life is primarily addressed by general biology. On the other hand, the reasons why organisms change and diversify are regarded as the purview of evolutionary biology. While the field of genetics dominates the topic of faithful heritability, the structure and function of cells is the domain of cellular biologists. Further yet, the mystery of how individual organisms maintain

their self-integrity and what it means to be an organism is considered appropriate for the philosopher's perch. In contrast, why organisms are distributed as they are is the realm of ecology. Among these varied disciplines, selection has been the single uniting theoretical glue. In the conventional view, natural selection somehow hammers, shapes, and nudges endless iterations of purposeless genetic variations into constructive biological outcomes.

Accordingly, the evolutionary literature has tended to concentrate on issues of the precise targets of selection with the expectation that if these were sufficiently identified, definite answers might ensue. Instead, what is required is a fresh vantage on evolutionary development tasked to resolve the largest issues in biological and evolutionary development, offering coherent answers that had previously eluded Darwinists. Those paramount questions are surprisingly few. Are evolutionary processes random or not? If not, why not? Is there any purpose to the billions of years of evolution that have been documented? If so, what is its deterministic aim? If evolution achieves direction, what force or combination of forces propel it?

Beyond this limited palette, five further issues and their related questions require explanation (Miller 2016a). First, expressly how is heritable variation achieved? Is genetic transmission almost entirely vertical in eukaryotes, or are horizontal genetic exchanges commonplace? Secondly, is selection ultimate causation or just one force among others? Third, is genetic inheritance the authentic controlling process in evolutionary development? Is biology just related to gene frequencies as explicitly taught, or are there other factors to consider? Fourth, is evolution random or not? If evolution is not random, what is the identifiable object of selection? And lastly, why are all multicellular eukaryotes holobionts without exception?

Fortunately, the last decades have provided a wellspring of illuminating research and provocative theorization. These are enabling explorations of biological and evolutionary development along pathways inconceivable to Darwin, his contemporaries, and initial successors. Two specific advances have been singularly important. First among these is the experimental and theoretical research confirming that all cells are cognitive self-referential agents (Baluška and Mancuso 2009, Shapiro 2011, Trewavas and Baluška 2011, Miller 2013, 2016a, 2018, Dodig-Crnkovic 2014, Lyon 2015). Crucially, cognition is present at every scale and defines life (Ford 2004, 2009, 2017, Trewavas and Baluška 2011, Miller 2013, 2016a, Baluška and Levin 2016, Vallverdú et al. 2018, Reber 2019, Baluška et al. 2021, 2022). Critical research substantiates an expansive suite of cellular faculties that were unimagined a mere two decades ago (Ford 2004, 2009, 2017, Lyon et al. 2021). True, cellular awareness is limited. Yet, it is effective and of sufficient magnitude to permit cells and cellular microbes to assess, communicate and deploy information to consistently support their individual homeorhetic preferences. Homeorhesis denotes a dynamical system that tends to return to a particular trajectory of energetic flux as opposed to the earlier concept of homeostatic equilibrium. (Miller 2013, 2016a, Baluška and Levin 2016, Miller et al. 2020a). Consequently, in a cognitive frame, information processing is the core cellular activity and underlies all resulting cell-cell communications that lead to the full array of biological outcomes. Most importantly, basal cognition does not merely enable collaboration, cooperation, co-dependency, and effective competition among cells but specifically impels it (Ben-Jacob and

Levine 2006, Ben-Jacob 2009, Miller 2016a, 2018, Miller and Torday 2018, Miller et al. 2020a,b). The basis of these conjoining actions is the cellular capacity to measure informational inputs. In so doing, each cell can engage in non-random intentional actions through cognitive information processing. Consequently, cognitive cells should be appraised as deliberate measuring instruments (Miller 2016a, Miller et al. 2019, 2020a,b, Baluška and Miller 2018, Baluška et al. 2021, 2022). Further, and most critically, those measurements are directly aimed at sustaining cellular homeorhesis versus the constant flow of environmental stimuli to protect the self-identity of every cell. This process, over time, is adaptive evolution, assuring the continuous cellular assimilation of the environment.

The second requisite shift critical to a productive reappraisal of Neodarwinism is our contemporary understanding of the multicellular eukaryotic form. Metagenomic techniques have revealed that all multicellular eukaryotes are holobionts as intimate entwined, reciprocating partnerships between eukaryotic cells and a vast microbial cohort (Miller 2016b). These vast confederacies are linked cellular ecologies with constituents of mixed cellular species that function together so seamlessly as to act as a single being but is manifestly not. It has only been with the recent advent of advanced genomic and metagenomic analysis that the astounding extent of microbial participation in eukaryotic life could be adequately grasped (Miller 2016b). Pertinently though, the collaborations that vitalize this collective form of life are exactly centered within ubiquitous cognition and its adjunctive cell-cell communication (Schauder and Bassler 2001, Visick and Fuqua 2005, Torday and Rehan 2012). Consequently, Darwinian evolution must be recast as an exploration of why linkages of these specific participants consistently recapitulate as a vast totality of intimately reciprocating ecologies as reproducing holobionts (Miller 2013, 2016a).

In addition to these essentials, other transformative elements are required to compel a new evolutionary narrative. Chief among these is our burgeoning understanding of the complexities and extent of cell-cell communication galvanized by cellular cognition. Crucially, how cognitive cells appraise information and deploy it can now be more effectively analyzed. Critical, too, has been the several decade-long accumulation of knowledge about epigenetic (non-genetic influences on gene expression) impacts and their heritable transmission, effecting both immediate and heritable changes on holobionts (Jablonka et al. 1992, Jablonka and Lamb 1998, Skinner 2015) Skinner 2015). Until just a few years ago, epigenetic influences were considered merely transient and arbitrated through natural selection (Feng et al. 2010, Hourri-Zeevi and Rechavi 2017). For decades, biologists remained averse to accepting the crucial role of epigenetics in evolutionary development, tainted by disdain for previously discarded Larmarckianism that had championed the possibility of inheritance of acquired traits. Yet, contemporary research asserts that a surprisingly consequential range of non-random epigenetic influences affect flexible genomes, assuming a substantial role in evolutionary development (Jablonka and Lamb 2008, Laland et al. 2015, Torday and Miller 2020, Miller et al. 2021). Therefore, the prior presumption of strict vertical inheritance is no longer tenable.

The authority of 20th century Neodarwinism rested on its confident assumption that evolution is the chronicle of differential fitness of heritable variations resulting from random genetic mutations within central genomes (Bowler 1989, Poelwijk et al.

2007). Within that framework, it seemed logical that evolution can be reasonably ascribed to a matter of changing gene frequencies disciplined by natural selection (Koonin 2009). However, 21st century research animates a thorough rethinking of genetic variation and evolutionary development. Consequently, Cognition-Based Evolution (CBE) merely follows the time-honored scientific tradition of periodic revision of any dominating theory based on fresh evidence. It was no different with early 20th century Darwinists. When confronted with the newly evolving science of genetics, they accommodated it by folding its initial findings into the standard architecture of Darwinism, thereby expanding it into an amended Modern Synthesis. However, there is a salient difference in this present revisionary instance compared to any prior. CBE is not just a further appendage to Darwinism but a thoroughly disruptive reconceptualization. Specifically, it argues that evolution is an informational interactome based on self-referential cellular dynamics and not a direct result of natural selection or gene frequencies.

Renaissance artists used compositional chiaroscuro to create an intense, dramatic light in their canvases, heightening their emotional tension. Originated by Leonardo Da Vinci in the late 15th century, these powerful effects were exemplified in the works of Caravaggio with their arresting contrasts between light and shadow. Although superficial viewing of one of these paintings suggests that the details are singularly focused within the brilliantly highlighted features of the figures, close inspection of any of these canvases reveals that these master artists paid meticulous attention to every aspect of the shadows. They instinctively understood that the complexity of the shadows required their intense concentration since they were as consequential to the whole as any intensely illuminated portion. Consequently, they filled the large dark shadows with texture, gradation, and variety. In so doing, they were fulfilling a neuroesthetic impulse to achieve a specific type of symmetry, balance, and complexity (Correa-Herran et al. 2020). Experiments show that if the shadow details are graphically eliminated from the image, it is rendered lifeless. By analogy and due to both instinct and previous technological limitations, our concepts of evolutionary processes have been based on rigorous examination of what had been readily accessible in biological light. Now, well armed with fresh scientific evidence and technical advances, we can turn our methodical scrutiny to the rich details in biology's former shadows.

Indeed, the explicit focal difference between Neodarwinism and Cognition-Based Evolution is the gap between that metaphorical light and shadow, the seen and the unseen, the conspicuous macroorganic reproductive organisms, and the microscopic world of cells and microbes. Until recently, and unlike its brethren 21st century counterpart sciences such as chemistry or physics, biology was based primarily on field observations rather than laboratory experimentation. As an observational and descriptive field, evolutionary biology and evolutionary ecology have largely concentrated on the macroscopic form. Naturally, this scrutiny drove evolutionary theory to accommodate and rationalize those ready, limited observations. Although the microscope had been invented by the early 1600s, few evolutionary biologists in the prior century paid great attention to the microscopic sphere, their means of communication, or their immunological rules. These were of little interest compared to the intriguing world of our dazzling, visible plants and animals. The shadowed

microscopic details received much less scrutiny. Now, in our contemporary era, both the microscopic and macroorganic sides can be fully honored. Accordingly, evolutionary biology can be productively reappraised as a complex holobionic entanglement, perpetually and faithfully rooted within its cellular origins across planetary evolution (Miller 2013, 2016a, Miller and Torday 2018, Miller et al. 2020a).

From this new ground state, a cohesive integrated evolutionary path emerges, connecting the primordial unicellular forms to the complexities of multicellular life. Through this means, some long-contested questions are settled. Does evolution have any identifiable direction? Are there any exact principles of evolution akin to physical laws? If not, are there cellular rules that can be identified that permit useful prediction of biological outcomes? Is creativity exclusive to humankind, or is it evident at all living scales? Is natural selection the true shaping force in evolution as its ultimate causation? If not, what else is driving biological outcomes? Is it true that our evolutionary narrative reduces to gene frequencies as population geneticists contend, or do other factors have paramountcy? This volume will address each of those dilemmas.

As is always the case, fresh questions naturally derive from within those answers. For example, what are the contextual behaviors of the constituent cells within those tissue ecologies that comprise us as holobionts? Why do multicellular eukaryotes engage in an obligatory recapitulation through a unicellular stage? Why is there a continued assumption that the microbial fraction of a holobiont is little more than a consequential appendage instead of an essential participant (Miller 2016a, Corning and Szathmáry 2015, Theis et al. 2016)? Most pertinently, why has the role of universal basal cognition in biological development been previously ignored by most biologists?

Beyond these readily apparent questions, CBE stimulates several unique queries that have been overlooked in prior considerations of evolutionary development. First, ‘Who is the observer and who is a participant?’ The other, ‘Who is serving and who is being served?’ (Torday and Miller 2016). These two lead to the most essential question in biology that is only conceivable within a cognitive framework that energizes cooperative engineering between the cellular domains and the virome: ‘Whose problems are being solved?’

One of the reasons that these have not been previously explored is that some of the answers do not fit earlier preconceived notions of biological hierarchies. Indeed, as will be explained, we are not the unambivalent aim of evolutionary development on the planet. Instead, evidence indicates that the only continuous direction in evolution is the consistent perpetuation of the four elemental domains, comprised by three cellular domains (Prokaryota, Archaea, Eukaryota), and the virome that functions as its flexible intermediary (Miller and Torday 2018). These primordial forms of life, and only these, have exerted permanent collective dominion over the planet for billions of years. All the stunning forms of visible life that engross us are their aggregates. Necessarily, then, the essential cellular constituents of each of those creatures represent the central action of life on the planet.

In comparison, the macroorganic species that rivet our attention are transient planetary occupants. Mounting evidence supports the disquieting conclusion that the visible organisms that form the light of biology to our keen but superficial

appraisal are largely subordinate to our invisible co-partners in the realm of shadows. Disconcerting as it might seem, the unicellular world achieves its continuous protection and permanent planetary place through us. Once this is grasped, an in-depth reappraisal of evolution is justified based on self-referential cellular requisites and the collective, collaborative, and competitive behaviors that are its consequence. The pertinent details lie in their efficient patterns of cell-cell communication and the intricacies of the informational matrix that permits their conjoint action (Torday and Rehan 2012, Miller 2018, Miller et al. 2020b).

Neodarwinism has dominated evolution over the last half-century, melding natural selection with an early, limited grasp of genetics. Random genetic variations, the absolute primacy of natural selection, and the presumption that the macroorganic reproductive unit represents the obvious target of selection are its principle tenets. Yet, each of these is now known to be incorrect. Consequently, evolution and biological development can now undergo a comprehensive re-evaluation based on the specific qualities of cognition that trigger cell-cell signaling of shared information among reciprocating, receptive cells. From within this new, compelling framework, a fresh universal synthesis emerges. Correctly centering evolutionary biology within cellular cognition places it squarely within the realm of measurement. At long last, evolutionary biology is propelled beyond descriptive associations and correlations into the realm of testable predictions subject to refutation. It is only in this way that biology can meet Popper's Falsification Principle—for a theory to be considered scientific, it must be testable so that it might be proved false (Helfenbien and DeSalle 2005).

Achieving this goal rests on scientific advances in microbiology, metagenomics, molecular biology, ecology, and immunology. All of these fields have dramatically progressed in the last decades. Prior to CBE, evolutionary biology had yet to fully incorporate them. Based on accumulated advances across the scientific spectrum, a surprising central principle of life has been uncovered. The universal bond of cellular life is the protection of the self-integrity of the collaborating participants (Miller et al. 2019). Cells have learned that there is a common currency of life. Survival is best attained by being in service to others.

It is part of human nature that what we see is often based on inherent presumptions. As John Lubbock, the British naturalist, keenly observed: "What we see depends mainly on what we look for". Consequently, generations of scholars have attributed evolutionary development to natural selection and presumed that it could shape random genetic variations if given enough time. This is evolution by accident. In its stead, Cognition-Based Evolution offers an unreservedly different perspective. Biological and evolutionary development is bound by the shared cognitive awareness of the three cellular domains and their resulting patterns of co-engineering with their companion virome, enjoined in a continuous, common planetary narrative for over 3.8 billion years. As the physician and scientist Jon Lieff (2020) elegantly concludes in 'The Secret Language of cells', "Although cells are considered the most basic characteristic that defines life, it is actually the conversations among cells, and also the conversations that take place inside them, that determines biological activity and produces the essence of life". That communication has one perpetual aim—to protect the integrity of self-aware cells. To succeed, cells are equipped to sense and

assess environmental information to permit their own self-directed and intelligence-based non-random adaptations. With this as the common cellular nomenclature, CBE unmoors evolution from its observational and descriptive roots and refashions biology into the scientific study of the cellular measurement of information and its productive communication. Consequently, the primary focus of biology shifts from cataloging what can be seen and counted with our eyes to the precise measurement of cellular dynamics at the microscopic scale.

CBE answers many confounding questions that have bedeviled evolutionary biology for over 150 years. Yet, undoubtedly, and in requisite scientific symmetry, the resolution of old riddles bindingly equates with the birth of parallel unknowns. And each of these fresh puzzles will stimulate its own dogged and creative inquiries, fathomed through pioneering and unconventional solutions that will serve to reveal the next set of mysteries.

*“Discovery follows discovery. Each both raising and answering questions, each ending a long search and each providing the new instruments for a new search”.*

—Robert Oppenheimer, physicist

## References

- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology* 7(902).
- Baluška, F. and Mancuso, S. 2009. Deep evolutionary origins of neurobiology: Turning the essence of “neural” upside-down. *Communicative & Integrative Biology* 2(1): 60–65.
- Baluška, F. and Miller, Jr, W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1–9.
- Baluška, F., Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Baluška, F., Reber, A.S. and Miller, W.B. 2022. Cellular sentience as the primary source of biological order and evolution. *Biosystems* 218: 104694.
- Ben-Jacob, E. 2009. Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences* 1178: 78–90.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197–214.
- Bowler, P.J. 1989. *Evolution: The History of an Idea*. Berkeley, CA, United States: University of California Press.
- Corning, P.A. and Szathmáry, E. 2015. “Synergistic selection”: A Darwinian frame for the evolution of complexity. *Journal of Theoretical Biology* 371: 45–58.
- Correa-Herran, I., Aleem, H. and Grzywacz, N. 2020. Evolution of Neuroaesthetic Variables in Portrait Paintings throughout the Renaissance. *Entropy*: 22(2): 146.
- Darwin, C. 2004. *On the Origin of Species, 1859*. United Kingdom: Routledge.
- Dobzhansky, T. 2013. Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher*, 75(2): 87–91.
- Didig-Crnkovic, G. 2014. Modeling Life as Cognitive Info-Computation. *In: A. Beckmann (ed.). Computability In Europe*. Berlin: Springer.
- Feng, S., Jacobsen, S.E. and Reik, W. 2010. Epigenetic Reprogramming in Plant and Animal Development. *Science* 330(6004): 622–627.
- Ford, B.J. 2004. Are Cells Ingenious? *Microscope* 52(3/4): 135–144.
- Ford, B.J. 2009. On Intelligence in Cells: The Case for Whole Cell Biology. *Interdisciplinary Science Reviews* 34(4): 350–365.

- Ford, B.J. 2017. Cellular intelligence: Microphenomenology and the realities of being. *Progress in Biophysics and Molecular Biology* 131: 273–287.
- Futuyma, D.J. 2017. Evolutionary biology today and the call for an extended synthesis. *Interface Focus* 7(5): 20160145.
- Helfenbein, K.G. and DeSalle, R. 2005. Falsifications and corroborations: Karl Popper’s influence on systematics. *Molecular Phylogenetics and Evolution* 35(1): 271–280.
- Houri-Zeevi, L. and Rechavi, O. 2017. A Matter of Time: Small RNAs Regulate the Duration of Epigenetic Inheritance. *Trends in Genetics* 33(1): 46–57.
- Huxley, T.H. 1887. On the Reception of the ‘Origin of Species’. pp. 179–204. *In*: F. Darwin (ed.). *The life and letters of Charles Darwin, including an autobiographical chapter*. London: John Murray.
- Jablonka, E. and Lamb, M.J. 1998. *Epigenetic Inheritance and Evolution: The Lamarckian Dimension*. Oxford, UK: Oxford University Press.
- Jablonka, Eva, Lachmann, M. and Lamb, M.J. 1992. Evidence, mechanisms and models for the inheritance of acquired characters. *Journal of Theoretical Biology* 158(2): 245–268.
- Jablonka, Eva and Lamb, M.J. 2008. *The Epigenome In Evolution: Beyond The Modern Synthesis*. *Vosgis Herald* 12.
- Koonin, E. V. 2009. Darwinian evolution in the light of genomics. *Nucleic Acids Research* 37(4): 1011–1034.
- Koonin, Eugene V. 2012. *The logic of chance: the nature and origin of biological evolution*. Upper Saddle River, NJ: Pearson Education.
- Laland, K.N., Uller, T., Feldman, M.W., Sterelny, K., Müller, G.B., Moczek, A., ... Odling-Smee, J. 2015. The extended evolutionary synthesis: its structure, assumptions and predictions. *In: Proceedings of the Royal Society B: Biological Sciences* (Vol. 282, p. 20151019).
- Lieff, J. 2020. *The Secret Language of Cells: What Biological Conversations Tell Us About the Brain-Body Connection, the Future of Medicine, and Life Itself*. Dallas, Texas: BenBella Books.
- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).
- Lyon, P., Keijzer, F., Arendt, D. and Levin, M. 2021. Reframing cognition: getting down to biological basics. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376(1820): 20190750.
- Majumdar, S. and Pal, S. 2017. Bacterial intelligence: imitation games, time-sharing, and long-range quantum coherence. *Journal of Cell Communication and Signaling* 11(3): 281–284.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016a. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2016b. The Eukaryotic Microbiome: Origins and Implications for Fetal and Neonatal Life. *Frontiers in Pediatrics* 4(96).
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1–26.
- Miller, W.B., Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.
- Miller, W.B., Enguita, F.J. and Leitão, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.
- Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.
- Miller, W.B., Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of ‘self’. *Progress in Biophysics and Molecular Biology* 142: 54–74.
- Miller, W.B., Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.
- Moss, L. 2012. Is the philosophy of mechanism philosophy enough? *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 43(1): 164–172.
- Nicholson, D. J. 2012. The concept of mechanism in biology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 43(1): 152–163.

- Poelwijk, F.J., Kiviet, D.J., Weinreich, D.M. and Tans, S.J. 2007. Empirical fitness landscapes reveal accessible evolutionary paths. *Nature* 445(7126): 383–386.
- Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness* (Illustrate). New York, NY, USA: Oxford University Press.
- Schauder, S. and Bassler, B.L. 2001. The languages of bacteria. *Genes & Development* 15(12): 1468–1480.
- Scheiner, S.M. 2010. Toward a Conceptual Framework for Biology. *The Quarterly Review of Biology* 85(3): 293–318.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Skinner, M.K. 2015. Environmental Epigenetics and a Unified Theory of the Molecular Aspects of Evolution: A Neo-Lamarckian Concept that Facilitates Neo-Darwinian Evolution. *Genome Biology and Evolution* 7(5): 1296–1302.
- Theis, K.R., Dheilly, N.M., Klassen, J.L., Brucker, R.M., Baines, J.F., Bosch, T.C.G., ... Bordenstein, S.R. 2016. Getting the Hologenome Concept Right: an Eco-Evolutionary Framework for Hosts and Their Microbiomes. *MSystems* 1(2).
- Torday, J.S. 2012. *Evolutionary Biology: Cell-Cell Communication, and Complex Disease* (1st ed.). Hoboken, New Jersey: Wiley-Blackwell.
- Torday, J.S. 2015. A Central Theory of Biology. *Medical Hypotheses* 85(1): 49–57.
- Torday, J.S. and Miller, W.B. 2016. Biologic relativity: Who is the observer and what is observed? *Progress in Biophysics and Molecular Biology*, 121(1): 29–34.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Torday, J.S. and Rehan, V.K. 2012. *Evolutionary Biology, Cell-Cell Communication and Complex Disease*. Hoboken, New Jersey: Wiley-Blackwell.
- Trewavas, A.J. and Baluška, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221–1225.
- Vallverdú, J., Castro, O., Mayne, R., Talanov, M., Levin, M., Baluška, F., ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57–70.
- Visick, K.L. and Fuqua, C. 2005. Decoding Microbial Chatter: Cell-Cell Communication in Bacteria. *Journal of Bacteriology* 187(16): 5507–5519.

## Introduction

- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology* 7(902).
- Baluška, F. and Mancuso, S. 2009. Deep evolutionary origins of neurobiology: Turning the essence of "neural" upside-down. *Communicative & Integrative Biology* 2(1): 60-65.
- Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Baluška, F. , Reber, A.S. and Miller, W.B. 2022. Cellular sentience as the primary source of biological order and evolution. *Biosystems* 218: 104694.
- Ben-Jacob, E. 2009. Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences* 1178: 78-90.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197-214.
- Bowler, P.J. 1989. *Evolution: The History of an Idea*. Berkeley, CA, United States: University of California Press.
- Corning, P.A. and Szathmáry, E. 2015. "Synergistic selection": A Darwinian frame for the evolution of complexity. *Journal of Theoretical Biology* 371: 45-58.
- Correa-Herran, I. , Aleem, H. and Grzywacz, N. 2020. Evolution of Neuroaesthetic Variables in Portrait Paintings throughout the Renaissance. *Entropy*: 22(2): 146.
- Darwin, C. 2004. *On the Origin of Species, 1859*. United Kingdom: Routledge.
- Dobzhansky, T. 2013. Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher*, 75(2): 87-91.
- Dodig-Crnkovic, G. 2014. Modeling Life as Cognitive Info-Computation. In: A. Beckmann (ed.). *Computability In Europe*. Berlin: Springer.
- Feng, S. , Jacobsen, S.E. and Reik, W. 2010. Epigenetic Reprogramming in Plant and Animal Development. *Science* 330(6004): 622-627.
- Ford., B.J . 2004. Are Cells Ingenious? *Microscope* 52(3/4): 135-144.
- Ford, B.J. 2009. On Intelligence in Cells: The Case for Whole Cell Biology. *Interdisciplinary Science Reviews* 34(4): 350-365.
- Ford, B.J. 2017. Cellular intelligence: Microphenomenology and the realities of being. *Progress in Biophysics and Molecular Biology* 131: 273-287.
- Futuyma, D.J. 2017. Evolutionary biology today and the call for an extended synthesis. *Interface Focus* 7(5): 20160145.
- Helpfenbein, K.G. and DeSalle, R. 2005. Falsifications and corroborations: Karl Popper's influence on systematics. *Molecular Phylogenetics and Evolution* 35(1): 271-280.
- Houri-Zeevi, L. and Rechavi, O. 2017. A Matter of Time: Small RNAs Regulate the Duration of Epigenetic Inheritance. *Trends in Genetics* 33(1): 46-57.
- Huxley, T.H. 1887. On the Reception of the 'Origin of Species'. pp. 179-204. In: F. Darwin (ed.). *The life and letters of Charles Darwin, including an autobiographical chapter*. London: John Murray.
- Jablonka, E. and Lamb, M.J. 1998. *Epigenetic Inheritance and Evolution: The Lamarckian Dimension*. Oxford, UK: Oxford University Press.
- Jablonka, Eva , Lachmann, M. and Lamb, M.J. 1992. Evidence, mechanisms and models for the inheritance of acquired characters. *Journal of Theoretical Biology* 158(2): 245-268.
- Jablonka, Eva and Lamb, M.J. 2008. *The Epigenome In Evolution: Beyond The Modern Synthesis*. Vösgis Herald 12.
- Koonin, E. V. 2009. Darwinian evolution in the light of genom cs. *Nucleic Acids Research* 37(4): 1011-1034.
- Koonin, Eugene V. 2012. *The logic of chance: the nature and origin of biological evolution*. Upper Saddle River, NJ: Pearson Education.
- Laland, K.N. , Uller, T. , Feldman, M.W. , Sterelny, K. , Muller, G.B. , Moczek, A. , ... Odling-Smee, J. 2015. The extended evolutionary synthesis: its structure, assumptions and predictions. In: *Proceedings of the Royal Society B: Biological Sciences* (Vol. 282, p. 20151019).
- Lieff, J. 2020. *The Secret Language of Cells: What Biological Conversations Tell Us About the Brain-Body Connection, the Future of Medicine, and Life Itself*. Dallas, Texas: BenBella Books.

- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).
- Lyon, P. , Keijzer, F. , Arendt, D. and Levin, M. 2021. Reframing cognition: getting down to biological basics. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376(1820): 20190750.
- Majumdar, S. and Pal, S. 2017. Bacterial intelligence: imitation games, time-sharing, and long-range quantum coherence. *Journal of Cell Communication and Signaling* 11(3): 281-284.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016a. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2016b. The Eukaryotic Microbiome: Origins and Implications for Fetal and Neonatal Life. *Frontiers in Pediatrics* 4(96).
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Balugka, F. and Torday, J.S. 2020a. Cellular genomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Enguita, F.J. and Leitdo, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.
- Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2019. Biological evolution as defense of 'self'. *Progress in Biophysics and Molecular Biology* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2020b. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Moss, L. 2012. Is the philosophy of mechanism philosophy enough? *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 43(1): 164-172.
- Nicholson, D. J. 2012. The concept of mechanism in biology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 43(1): 152-163.
- Poelwijk, F.J. , Kiviet, D.J. , Weinreich, D.M. and Tans, S.J. 2007. Empirical fitness landscapes reveal accessible evolutionary paths. *Nature* 445(7126): 383-386.
- Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York, NY, USA: Oxford University Press.
- Schauder, S. and Bassler, B.L. 2001. The languages of bacteria. *Genes & Development* 15(12): 1468-1480.
- Scheier, S.M. 2010. Toward a Conceptual Framework for Biology. *The Quarterly Review of Biology* 85(3): 293-318.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Skinner, M.K. 2015. Environmental Epigenetics and a Unified Theory of the Molecular Aspects of Evolution: A Neo-Lamarckian Concept that Facilitates Neo-Darwinian Evolution. *Genome Biology and Evolution* 7(5): 1296-1302.
- Theis, K.R. , Dheilly, N.M. , Klassen, J.L. , Brucker, R.M. , Baines, J.F. , Bosch, T.C.G. , Bordenstein, S.R. 2016. Getting the Hologenome Concept Right: an Eco-Evolutionary Framework for Hosts and Their Microbiomes. *MSystems* 1(2).
- Torday, J.S. 2012. *Evolutionary Biology: Cell-Cell Communication, and Complex Disease (1st ed.)*. Hoboken, New Jersey: Wiley-Blackwell.
- Torday, J.S. 2015. A Central Theory of Biology. *Medical Hypotheses* 85(1): 49-57.
- Torday, J.S. and Miller, W.B. 2016. Biologic relativity: Who is the observer and what is observed? *Progress in Biophysics and Molecular Biology*, 121(1): 29-34.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Torday, J.S. and Rehan, V.K. 2012. *Evolutionary Biology, Cell-Cell Communication and Complex Disease*. Hoboken, New Jersey: Wiley-Blackwell.
- Trewavas, A.J. and Balugka, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221-1225.

Vallverdú, J. , Castro, O. , Mayne, R. , Talanov, M. , Levin, M. , Baluška, F. , ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57-70.

Visick, K.L. and Fuqua, C. 2005. Decoding Microbial Chatter: Cell-Cell Communication in Bacteria. *Journal of Bacteriology* 187(16): 5507-5519.

## Evolution in the 20th Century

Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178: 106-119.

Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.

Baverstock, K. 2019. Polygenic scores: Are they a public health hazard? *Progress in Biophysics and Molecular Biology* 149: 4-8.

Bowler, P.J. 1983. *The Eclipse of Darwinism: Anti-Darwinian Evolution Theories in the Decades around 1900* (1st ed.). Johns Hopkins University Press.

Bowler, P.J. 2003. *Evolution: The History of an Idea* ( 3rd ed.). Berkeley (California): University of California Press.

Caporale, L. 2003. *Darwin In the Genome: Molecular Strategies in Biological Evolution*. New York City, NY, USA: McGraw-Hill.

Caporale, L.H. and Doyle, J. 2013. In Darwinian evolution, feedback from natural selection leads to biased mutations. *Annals of the New York Academy of Sciences* 1305: 18-28.

Colson, P. and Raoult, D. 2012. Lamarckian evolution of the giant Mimivirus in allopatric laboratory culture on amoebae. *Frontiers in Cellular and Infection Microbiology* 2(91).

Corning, P.A. 2020. Beyond the modern synthesis: A framework for a more inclusive biological synthesis. *Progress in Biophysics and Molecular Biology* 153: 5-12.

Darwin, C.R. 1859. *On the origin of species by means of natural selection* (1st ed.). London: John Murray.

Darwin, C.R. 1871. *The Descent of Man and Selection in Relation to Sex*, Volume 2. Cambridge: Cambridge University Press.

Dawkins, R. 1989. *The Selfish Gene* ( 2nd ed.). Oxford, UK: Oxford University Press.

de Queiroz, K. 2005. Ernst Mayr and the modern concept of species. *Proceedings of the National Academy of Sciences* 102(suppl 1): 6600-6607.

Fodor, J. and Piattelli-Palmarini, M. 2010. *What Darwin Got Wrong*. New York, NY, USA: Farrar, Straus and Giroux.

Goldenfeld, N. and Woese, C. 2011. Life is Physics: Evolution as a Collective Phenomenon Far From Equilibrium. *Annual Review of Condensed Matter Physics* 2: 375-399.

Gould, Stephen J. 1977. The Return of Hopeful Monsters. *Natural History* 86: 22-30.

Gould, Stephen J. 1982. *The uses of heresy: An introduction to Richard Goldschmidt's The Material Basis of Evolution*. New Haven: Yale University Press.

Gould, Stephen Jay . 2002. *The Structure of Evolutionary Theory*. Harvard: Belknap Press.

Graffon, R.Q. , Nelson, H.W. , Lambie, N.R. and Wyrwoll, P.R. 2013. *A Dictionary of Climate Change and the Environment: Economics, Science, and Policy*. Northampton, MA, USA: Edward Elgar Publishing Ltd.

Gray, M.W. 2017. Lynn Margulis and the endosymbiont hypothesis: 50 years later. *Molecular Biology of the Cell* 28(10): 1285-1287.

Houle, D. , Pelabon, C. , Wagner, G.P. and Hansen, T.F. 2011. Measurement and Meaning in Biology. *The Quarterly Review of Biology* 86(1): 3-34.

Jablonka, E. 1999. *Epigenetic Inheritance and Evolution: The Lamarckian Dimension*. Oxford: Oxford University Press.

Jablonka, E. and Lamb, M.J. 2008. The Epigenome In Evolution: Beyond The Modern Synthesis. *Vosg s Herald* 12.

Kimura, M. 1968. Evolutionary Rate at the Molecular Level. *Nature* 217(5129): 624-626.

Kimura, M. 1991. Recent development of the neutral theory viewed from the Wrightian tradition of theoretical population genetics. *Proceedings of the National Academy of Sciences* 88(14):

5969-5973.

- Koonin, E.V. 2009. Darwinian evolution in the light of genomics. *Nucleic Acids Research* 37(4): 1011-1034.
- Krumbhaar, E.B. 1931. Erasmus Darwin and His Relation to the Doctrine of Evolution. *Annals of Medical History* 3(5): 487-500.
- Laland, K. , Uller, T. , Feldman, M. , Sterelny, K. , Muller, G.B. , Moczek, A. , ... Strassmann, J.E. 2014. Does evolutionary theory need a rethink? *Nature* 514(7521): 161-164.
- Laland, K.N. , Uller, T. , Feldman, M.W. , Sterelny, K. , Muller, G.B. , Moczek, A. , ... and Odling-Smee, J. 2015. The extended evolutionary synthesis: its structure, assumptions and predictions. *Proceedings of the Royal Society B: Biological Sciences* 282(1813): 20151019.
- Larson, E.J. 2004. *Evolution: The Remarkable History of a Scientific Theory*. New York City, NY, USA: Modern Library.
- Lewontin, R.C. 2010. *Not So Natural Selection*. New York City, NY, USA: The New York Review of Books.
- Marijuán, P.C. and Navarro, J. 2022. The biological information flow: From cell theory to a new evolutionary synthesis. *Biosystems* 213: 104631.
- Matthew, P. 1831. *On naval timber and arboriculture: with critical notes on authors who have recently treated the subject of planting*. Longman, Rees, Orme, Brown, and Green; London and Adam Black, Edinburgh.
- Mayr, E. 1942. *Systematics and the Origin of Species from the Viewpoint of a Zoologist*. New York City, NY, USA: Columbia University Press.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Balugka, F. and Torday, J.S. 2020. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Enguita, F.J. and Leitdo, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.
- Miller, W.B. and Torday, J. S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Müller, G.B. 2017. Why an extended evolutionary synthesis is necessary. *Interface Focus* 7(5): 20170015.
- Noble, D. 2020. Editorial: Charles Darwin, Jean-Baptiste Lamarck, and 21st century arguments on the fundamentals of biology. *Progress in Biophysics and Molecular Biology* 153: 1-4.
- Noble, D. 2021. The Illusions of the Modern Synthesis. *Biosemiotics* 14: 5-24.
- Ohta, T. and Gillespie, J.H. 1996. Development of Neutral and Nearly Neutral Theories. *Theoretical Population Biology* 49(2): 128-142.
- Pigliucci, M. 2007. Do We Need An Extended Evolutionary Synthesis? *Evolution* 61(12): 2743-2749.
- Provine, W.B. 2004. Ernst Mayr. *Genetics* 167(3): 1041-1046.
- Rampino, M.R. 2011. Darwin's error? Patrick Matthew and the catastrophic nature of the geologic record. *Historical Biology* 23(2-3): 227-230.
- Rose, M.R. and Oakley, T.H. 2007. The new biology: beyond the Modern Synthesis. *Biology Direct* 2: 30.
- Rosenberg, E. , Sharon, G. and Zilber-Rosenberg, I. 2009. The hologenome theory of evolution contains Lamarckian aspects within a Darwinian framework. *Environmental Microbiology* 11(12): 2959-2962.
- Ruse, M. 2008. 2. Alfred Russel Wallace, the Discovery of Natural Selection, and the Origins of Humankind. pp. 20-36. In: O. Harman (ed.). *Rebels, Mavericks, and Heretics in Biology*. New Haven: Yale University Press.
- Rybnikov, S.R. , Frenkel, Z.M. , Kirzhner, V.M. and Korol, A.B. 2015. Complex Dynamics of Multilocus Genetic Systems: A Revisit of Earlier Findings in Relation to Ecosystem Evolution. *Botanica Pacifica*.
- Shapiro, J.A. 2009. Revisiting the Central Dogma in the 21st Century. *Annals of the New York Academy of Sciences* 1178: 6-28.

- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Shapiro, J.A. 2016. The basic concept of the read-write genome: Mini-review on cell-mediated DNA modification. *Biosystems* 140: 35-37.
- Shapiro, J.A. 2021. Response to Denis Noble's Article "The Illusions of the Modern Synthesis", *Biosemiotics*. *Biosemiotics* 14: 73-78.
- Singer, E. 2009. *A Comeback for Lamarckian Evolution?* Cambridge, MA, USA: MIT Technology Review.
- Stearns, S. and Hoekstra, R. 2000. *Evolution: an Introduction*. Oxford, UK: Oxford University Press.
- Torday, J.S. 2015a. The cell as the mechanistic basis for evolution. *WIREs Systems Biology and Medicine* 7(5): 275-284.
- Torday, J.S. 2015b. A Central Theory of Biology. *Medical Hypotheses* 85(1): 49-57.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Witzany, G. 2010. Biocommunication and natural genome editing. *World Journal of Biological Chemistry* 1(11): 348.
- Woese, C.R. and Goldenfeld, N. 2009. How the Microbial World Saved Evolution from the Scylla of Molecular Biology and the Charybdis of the Modern Synthesis. *Microbiology and Molecular Biology Reviews* 73(1): 14-21.

## 21st Century Evolution

- Aerts, D. , Broekaert, J. , Gabora, L. and Sozzo, S. 2013. Quantum structure and human thought. *Behavioral and Brain Sciences* 36(3): 274-276.
- Al-Khalili, J. and McFadden, J. 2014. *Life on the Edge: The Coming of Age of Quantum Biology*. London: Bantam Press.
- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology* 7.
- Baluška, F. and Mancuso, S. 2009. Deep evolutionary origins of neurobiology: Turning the essence of "neural" upside-down. *Communicative & Integrative Biology* 2(1): 60-65.
- Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senomic versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Baluška, F. and Reber, A.S. 2021. The Biomolecular Basis for Plant and Animal Sentience: Senomic and Ephaptic Principles of Cellular Consciousness. *Journal of Consciousness Studies* 28(1-2): 31-49.
- Bannert, N. and Kurth, R. 2004. Retroelements and the human genome: New perspectives on an old relation. *Proceedings of the National Academy of Sciences* 101(Suppl 2): 14572-14579.
- Ben-Jacob, E. 2009. Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences* 1178: 78-90.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197-214.
- Bongard, J. and Levin, M. 2021. Living Things Are Not (20th Century) Machines: Updating Mechanism Metaphors in Light of the Modern Science of Machine Behavior. *Frontiers in Ecology and Evolution*, 9.
- Bray, D. 2009. *Wetware: A Computer in Every Living Cell*. New Haven: Yale University Press.
- Brüntrup, G. 2016. Emergent Panpsychism. pp. 48-72. In: *Panpsychism*. Oxford, UK: Oxford University Press.
- Chuang, J.S. , Frentz, Z. and Leibler, S. 2019. Homeorhesis and ecological succession quantified in synthetic microbial ecosystems. *Proceedings of the National Academy of Sciences* 116(30): 14852-14861.
- D'Ario, M. , Tavares, R. , Schiessl, K. , Desvoyes, B. , Gutierrez, C. , Howard, M. and Sablowski, R. 2021. Cell size controlled in plants using DNA content as an internal scale. *Science* 372(6547): 1176-1181.

D'Souza, G. , Waschina, S. , Pande, S. , Bohl, K. , Kaleta, C. and Kost, C. 2014. Less is more: selective advantages can explain the prevalent loss of biosynthetic genes in bacteria. *Evolution* 68(9): 2559-2570.

Damasio, A.R. 2019. *The Strange Order of Things: Life, Feeling, and the Making of Cultures* (Reprint). New York, NY: Vintage.

Dawkins, R. 1976. *The Selfish Gene*. Oxford, UK: Oxford University Press.

Dawkins, R. and Davis, N. 2017. *The Selfish Gene*. Macat Library.

De Loof, A. 2015. From Darwin's *On the Origin of Species* by Means of Natural Selection... to The evolution of Life with Communication Activity as its Very Essence and Driving Force (= Mega-Evolution). *Life: The Excitement of Biology* 3(3): 153-187.

Dodig-Crnkovic, G. 2014. Modeling life as cognitive info-computation. In *Computability in Europe*. Cham, Switzerland: Springer.

Feinberg, T.E. and Mallatt, J. 2020. Phenomenal Consciousness and Emergence: Eliminating the Explanatory Gap. *Frontiers in Psychology* 11.

Feschotte, C. and Gilbert, C. 2012. Endogenous viruses: insights into viral evolution and impact on host biology. *Nature Reviews Genetics* 13(4): 283-296.

Fields, C. , Glazebrook, J.F. and Levin, M. 2021. Minimal physicalism as a scale-free substrate for cognition and consciousness. *Neuroscience of Consciousness* 2021(2).

Ford, B.J. 2009. On Intelligence in Cells: The Case for Whole Cell Biology. *Interdisciplinary Science Reviews* 34(4): 350-365.

Ford, B.J. 2017. Cellular intelligence: Microphenomenology and the realities of being. *Progress in Biophysics and Molecular Biology* 131: 273-287.

Freddolino, P.L. and Tavazoie, S. 2012. Beyond Homeostasis: A Predictive-Dynamic Framework for Understanding Cellular Behavior. *Annual Review of Cell and Developmental Biology* 28: 363-384.

Friston, K. 2010. The free-energy principle: a unified brain theory? *Nature Reviews Neuroscience* 11(2): 127-138.

Friston, K. , Kilner, J. and Harrison, L. 2006. A free energy principle for the brain. *Trends in Cognitive Sciences* 13(7): 293-301.

Gagliano, M. , Renton, M. , Depczynski, M. and Mancuso, S. 2014. Experience teaches plants to learn faster and forget slower in environments where it matters. *Oecologia* 175: 63-72.

Galluzzi, L. , Kepp, O. and Kroemer, G. 2012. Mitochondria: master regulators of danger signalling. *Nature Reviews Molecular Cell Biology* 13(12): 780-788.

Gevers, D. , Knight, R. , Petrosino, J.F. , Huang, K. , McGuire, A.L. , Birren, B.W. , Huttenhower, C. 2012. The Human Microbiome Project: A Community Resource for the Healthy Human Microbiome. *PLoS Biology* 10(8): e1001377.

Groner, P. 2000. *Saicho: The Establishment of the Japanese Tendai School*. Honolulu, Hawaii: University of Hawaii Press.

Hameroff, S. 2021. 'Orch OR' is the most complete, and most easily falsifiable theory of consciousness. *Cognitive Neuroscience* 12(2): 74-76.

Hameroff, S. and Penrose, R. 1996. Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness. *Mathematics and Computers in Simulation* 40(3-4): 453-480.

Hameroff, S. and Penrose, R. 2014. Consciousness in the universe. *Physics of Life Reviews* 11(1): 39-78.

Howard, S.R. , Avarguès-Weber, A. , Garcia, J.E. , Greentree, A.D. and Dyer, A.G. 2019. Numerical cognition in honeybees enables addition and subtraction. *Science Advances* 5(2).

Ingber, D.E. 2003. Mechanosensation through integrins: Cells act locally but think globally. *Proceedings of the National Academy of Sciences* 100(4): 1472-1474.

Karpiński, S. and Szechyńska-Hebda, M. 2010. Secret life of plants. *Plant Signaling & Behavior* 5(11): 1391-1394.

Koonin, E.V. 2009. Darwinian evolution in the light of genomics. *Nucleic Acids Research* 37(4): 1011-1034.

Kramar, M. and Alim, K. 2021. Encoding memory in tube diameter hierarchy of living flow network. *Proceedings of the National Academy of Sciences* 118(10).

Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).

- Malkov, V.B. , Chemezov, O.V. and Malkov, A.V. 2020. Aperiodic Schrodinger Crystals. In: IOP Conference Series: Materials Science and Engineering (Vol. 969, p. 012026). IOP Publishing.
- Marchi, S. , Patergnani, S. and Pinton, P. 2014. The endoplasmic reticulum-mitochondria connection: One touch, multiple functions. *Biochimica et Biophysica Acta (BBA)-Bioenergetics* 1837(4): 461-469.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Balugka, F. and Torday, J.S. 2020a. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. and Torday, J. S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Niemann, H.-J. 2021. Popper, Darwin, and Biology. pp. 231-256. In: Z. Parusn Kova and D. Merritt (eds.). *Karl Popper's Science and Philosophy*. Cham, Switzerland: Springer.
- Nurse, P. 2020. *What is Life?: Understand Biology in Five Steps*. Oxford, UK: David Fickling Books.
- Ogbunugafor, C.B. 2020. A Reflection on 50 Years of John Maynard Smith's "Protein Space". *Genetics* 214(4): 749-754.
- Pinto, D. and Mascher, T. 2016. (Actino) Bacterial "intelligence": using comparative genomics to unravel the information processing capacities of microbes. *Current Genetics* 62(3): 487-498.
- Pookottil, R. 2013. *BEEM: Biological Emergence-based Evolutionary Mechanism: How Species Direct Their Own Evolution*. Cornwall, UK: Fossil Fish Publishing.
- Ramanathan, S. and Broach, J.R. 2007. Do cells think? *Cellular and Molecular Life Sciences* 64(14): 1801-1804.
- Ramstead, M.J.D. , Badcock, P.B. and Friston, K.J. 2018. Answering Schrödinger's question: A free-energy formulation. *Physics of Life Reviews* 24: 1-16.
- Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness*. Oxford, UK: Oxford University Press.
- Reber, A.S. and Balugka, F. 2021. Cognition in some surprising places. *Biochemical and Biophysical Research Communications* 564: 150-157.
- Reznikova, Z. and Ryabko, B. 2011. Numerical competence in animals, with an insight from ants. *Behaviour* 148(4): 405-434.
- Rodríguez-Rosario, C.A. , Frauenheim, T. and Aspuru-Guzik, A. 2013. Thermodynamics of quantum coherence.
- Roskelley, C.D. and Bissell, M.J. 1995. Dynamic reciprocity revisited: a continuous, bidirectional flow of information between cells and the extracellular matrix regulates mammary epithelial cell function. *Biochemistry and Cell Biology* 73(7-8): 391-397.
- Schrödinger, E. 1944. *What is Life? The Physical Aspect of the Living Cell*. Cambridge, UK: Cambridge University Press.
- Schrödinger, E. 1984. *General Scientific and Popular Papers*. p. 334. In: *Collected papers V. 4. General scientific and popular papers*. Friedrich Vieweg Und Sohn, Braunschweig/Wiesbaden, Germany.
- Shapiro, J.A. 2007. Bacteria are small but not stupid: cognition, natural genetic engineering and sociobacteriology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 38(4): 807-819.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Shapiro, J.A. 2021. All living cells are cognitive. *Biochemical and Biophysical Research Communications* 564: 134-149.
- Szathmáry, E. and Smith, J.M. 1995. The major evolutionary transitions. *Nature* 374(6519): 227-232.

- Tasoff, J. , Mee, M.T. and Wang, H.H. 2015. An Economic Framework of Microbial Trade. *Plos One*, 10(7): e0132907.
- Timsit, Y. and Gregoire, S.-P. 2021. Towards the Idea of Molecular Brains. *International Journal of Molecular Sciences* 22(21): 11868.
- Torday, J.S. 2018. Quantum Mechanics predicts evolutionary biology. *Progress in Biophysics and Molecular Biology* 135: 11-15.
- Torday, J.S. 2018. From cholesterol to consciousness. *Progress in Biophysics and Molecular Biology* 132: 52-56.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology* Cham, Switzerland: Springer.
- Trewavas, A.J. and Balugka, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221-1225.
- Vallverdú, J. , Castro, O. , Mayne, R. , Talanov, M. , Levin, M. , Baluška, F. , ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57-70.
- Visick, K.L. and Fuqua, C. 2005. Decoding Microbial Chatter: Cell-Cell Communication in Bacteria. *Journal of Bacteriology* 187(16): 5507-5519.
- Walker, S.I. and Davies, P.C.W. 2013. The algorithmic origins of life. *Journal of The Royal Society Interface* 10(79): 20120869.
- Williams, P. , Winzer, K. , Chan, W.C. and Camara, M. 2007. Look who's talking: communication and quorum sensing in the bacterial world. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362(1483): 1119-1134.
- Zhu, L. , Kim, S.-J. , Hara, M. and Aono, M. 2018. Remarkable problem-solving ability of unicellular amoeboid organism and its mechanism. *Royal Society Open Science* 5(12): 180396.

## **The Cellular Information Cycle and Biological Information Management**

- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology* 7.
- Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Ben-Jacob, E. 2009. Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences* 1178: 78-90.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197-214.
- Cárdenas-García, J.F. 2020. The Process of Info-Autopoiesis-the Source of all Information. *Biosemiotics* 199-221.
- Czárán, T. and Hoekstra, R.F. 2009. Microbial Communication, Cooperation and Cheating: Quorum Sensing Drives the Evolution of Cooperation in Bacteria. *PLoS ONE* 4(8): e6655.
- Davies, P. and Gregersen, N.H. (eds.). 2014. *Information and the nature of reality: from physics to metaphysics*. Cambridge University Press.
- De Loof, A. 2015a. From Darwin's On the Origin of Species by Means of Natural Selection... to The evolution of Life with Communication Activity as its Very Essence and Driving Force (= Mega-Evolution). *Life: The Excitement of Biology* 3(3): 153-187.
- De Loof, A. 2015b. Organic and Cultural Evolution can be Seamlessly Integrated Using the Principles of Communication and Problem-Solving: The Foundations for an Extended Evolutionary Synthesis (EES) as Outlined in the Mega-Evolution Concept. *Life: The Excitement of Biology* 2(4): 247-269.
- De Loof, A. 2017. The evolution of "Life": A Metadarwinian integrative approach. *Communicative & Integrative Biology* 10(3): e1301335.
- Deacon, T.W. 2011. *Incomplete Nature*. New York: W. W. Norton & Company.
- Dodig-Crnkovic, G. 2014. Modeling Life as Cognitive Info-computation. pp. 153-162. In: *Conference on Computability in Europe*, Springer, Cham.
- Eisenstein, E.M. and Eisenstein, D. 2006. A Behavioral Homeostasis Theory of Habituation and Sensitization: II. Further Developments and Predictions. *Reviews in the Neurosciences* 17(5).

- Farnsworth, K.D. , Nelson, J. and Gershenson, C. 2013. Living is Information Processing: From Molecules to Global Systems. *Acta Biotheoretica* 61(2): 203-222.
- Forshaw, S.D. 2016. The Third State: Toward a Quantum Information Theory of Consciousness. *NeuroQuantology* 14(1): 49-61.
- Agliano, M. , Renton, M. , Depczynski, M. and Mancuso, S. 2014. Experience teaches plants to learn faster and forget slower in environments where it matters. *Oecologia* 175: 63-72.
- Gabor, D. 1946. Theory of communication. Part 1: The analysis of information. *Journal of the Institution of Electrical Engineers-part III: radio and communication engineering* 93(26): 429-441.
- Hall, W.P. 2005. Biological nature of knowledge in the learning organisation. *The Learning Organization*, 12(2): 169-188.
- Ho, M.-W. 2008. *The Rainbow and the Worm: The Physics of Organisms* (2nd ed.). World Scientific Publishing Company.
- Lloyd, S. 2002. Computational Capacity of the Universe. *Physical Review Letters* 88(23): 237901.
- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).
- Marijuan, P.C. and Navarro, J. 2022. The biological information flow: From cell theory to a new evolutionary synthesis. *Biosystems* 213: 104631.
- Marijuán, P.C. , Navarro, J. and del Moral, R. 2015. How the living is in the world: An inquiry into the informational choreographies of life. *Progress in Biophysics and Molecular Biology* 119(3): 469-480.
- Marshall, W.F. 2019. Cellular Cognition: Sequential Logic in a Giant Protist. *Current Biology* 29(24): R1303-R1305.
- Matsui, T. 2001. Gauge symmetry and neural networks. pp. 271-280. In: *Fluctuating Paths and Fields*. World Scientific.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenome c Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Reber, A.S. , Marshall, P. and Balugka, F. 2022. Viral-Cellular Natural Engineering in Cognition-Based Evolution. *Communicative and Integrative Biology*. Accepted
- Miller, W.B. and Torday, J. S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2019. Biological Evolution as Defense of "Self". *Progress in and Molecular* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Noble, R. and Noble, D. 2017. Was the Watchmaker Blind? Or Was She One-Eyed? *Biology* 6(4): 47.
- Papineau, D. , She, Z. , Dodd, M.S. , Iacoviello, F. , Slack, J.F. , Hauri, E. , ... Little, C. T.S. 2022. Metabolically diverse primordial microbial communities in Earth's oldest seafloor-hydrothermal jasper. *Science Advances* 8(15).
- Pilorz, V. , Tam, S.K.E. , Hughes, S. , Pothecary, C.A. , Jagannath, A. , Hankins, M.W. , Peirson, S.N. 2016. Melanopsin Regulates Both Sleep-Promoting and Arousal-Promoting Responses to Light. *PLOS Biology* 14(6): e1002482.
- Proietti, M. , Pickston, A. , Graffitti, F. , Barrow, P. , Kundys, D. , Branciard, C. , ... Fedrizzi, A. 2019. Experimental test of local observer independence. *Science Advances* 5(9).
- Rankin, C.H. , Abrams, T. , Barry, R.J. , Bhatnagar, S. , Clayton, D.F. , Colombo, J. , ... Thompson, R.F. 2009. Habituation revisited: An updated and revised description of the behavioral characteristics of habituation. *Neurobiology of Learning and Memory* 92(2): 135-138.
- Santiana, M. , Ghosh, S. , Ho, B.A. , Rajasekaran, V. , Du, W.-L. , Mutsafi, Y. , ... Altan-Bonnet, N. 2018. Vesicle-Cloaked Virus Clusters Are Optimal Units for Inter-organismal Viral

Transmission. *Cell Host & Microbe* 24(2): 208-220.e8.

Sato, M. , Tsuji, T. , Yang, K. , Ren, X. , Dreyfuss, J.M. , Huang, T.L. , Tseng, Y.-H. 2020. Cell-autonomous light sensitivity via Opsin3 regulates fuel utilization in brown adipocytes. *PLOS Biology* 18(2): e3000630.

Sugihara, T. , Nagata, T. , Mason, B. , Koyanagi, M. and Terakita, A. 2016. Absorption Characteristics of Vertebrate Non-Visual Opsin, Opn3. *Plos One* 11(8): e0161215.

Szostak, J.W. 2003. Functional information: Molecular messages. *Nature* 423(6941): 689.

Torday, J.S. and Miller, W.B. 2016. Life is determined by its environment. *International Journal of Astrobiology* 15(4): 345-350.

Torday, J.S. and Miller, W.B. 2017. The resolution of ambiguity as the basis for life: A cellular bridge between Western reductionism and Eastern holism. *Progress in Biophysics and Molecular Biology* 131: 288-297.

Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.

Tozzi, A. and Peters, J.F. 2017. What is it like to be “the same”? *Progress in Biophysics and Molecular Biology* 133: 30-35.

Trewavas, A.J. and Balugka, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221-1225.

Vallverdu, J. , Castro, O. , Mayne, R. , Talanov, M. , Levin, M. , Baluška, F. , ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57-70.

Walker, S.I. and Davies, P.C.W. 2013. The algorithmic origins of life. *Journal of The Royal Society Interface* 10(79): 20120869.

Witzany, G. 2011. The agents of natural genome editing. *Journal of Molecular Cell Biology* 3(3): 181-189.

Witzany, G. 2016. The biocommunication method: On the road to an integrative biology. *Communicative & Integrative Biology* 9(2): e1164374.

Witzany, G. and Baluška, F. (eds.). 2012. *Biocommunication of Plants (Vol. 14)*. Berlin, Germany: Springer.

## The Senome

Agnati, L.F. , Balugka, F. , Barlow, P.W. and Guidolin, D. 2009. Mosaic, self-similarity logic and biological attraction principles. *Communicative & Integrative Biology* 2(6): 552-563.

Anvarian, Z. , Mykytyn, K. , Mukhopadhyay, S. , Pedersen, L.B. and Christensen, S.T. 2019. Cellular signalling by primary cilia in development, organ function and disease. *Nature Reviews Nephrology* 15(4): 199-219.

Atkin-Smith, G.K. and Poon, I.K.H. 2017. Disassembly of the Dying: Mechanisms and Functions. *Trends in Cell Biology* 27(2): 151-162.

Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178: 106-119.

Baluška, F. 2014. Life is more than a computer running DNA software. *World Journal of Biological Chemistry* 5(3): 275.

Baluška, F. and Mancuso, S. 2013. Root Apex Transition Zone As Oscillatory Zone. *Frontiers in Plant Science* 4(354).

Baluška, F. and Mancuso, S. 2014. Synaptic view of eukaryotic cell. *International Journal of General Systems* 43(7): 740-756.

Baluška, F. and Mancuso, S. 2018. Plant Cognition and Behavior: From Environmental Awareness to Synaptic Circuits Navigating Root Apices. pp. 51-77. *In: F. Baluska , M. Gagliano and G. Witzany (eds.). Memory and Learning in Plants*. Cham, Switzerland: Springer.

Baluška, F. and Mancuso, S. 2021. Individuality, self and sociality of vascular plants. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376(1821): 20190760.

Baluška, F. , Mancuso, S. , Volkmann, D. and Barlow, P. 2009. The ‘root-brain’ hypothesis of Charles and Francis Darwin. *Plant Signaling & Behavior* 4(12): 1121-1127.

- Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Baluška, F. and Reber, A.S. 2021. CBC-Clock Theory of Life Integration of cellular circadian clocks and cellular sentience is essential for cognitive basis of life. *BioEssays* 43(10): 2100121.
- Baluška, F. and Witzany, G. 2014. Life is more than a computer running DNA software. *World Journal of Biological Chemistry* 5(3): 275.
- Blackmore, S. 2016. Memes and the evolution of religion: We need memet cs, too. *Behavioral and Brain Sciences* 39: e5.
- Brenner, E.D. , Stahlberg, R. , Mancuso, S. , Vivanco, J. , Baluška, F. and Van Volkenburgh, E. 2006. Plant neurobiology: an integrated view of plant signaling. *Trends in Plant Science* 11(8): 413-419.
- Cai, X. , Wang, X. , Patel, S. and Clapham, D.E. 2015. Insights into the early evolution of animal calcium signaling machinery: A unicellular point of view. *Cell Calcium* 57(3): 166-173.
- Cárdenas-García, J.F. 2020. The Process of Info-Autopoiesis-the Source of all Information. *Biosemitotics* 13(2): 199-221.
- Claverie, J.-M. 2006. Viruses take center stage in cellular evolution. *Genome Biology* 7(6): 110.
- De Loof, A. 2015. From Darwin's On the Origin of Species by Means of Natural Selection... to The evolution of Life with Communication Activity as its Very Essence and Driving Force (= Mega-Evolution). *Life: The Excitement of Biology* 3(3): 153-187.
- De Loof, A. 2017. The evolution of "Life": A Metadarwinian integrative approach. *Communicative & Integrative Biology* 10(3): e1301335.
- Demekas, D. , Parr, T. and Friston, K.J. 2020. An Investigation of the Free Energy Principle for Emotion Recognition. *Frontiers in Computational Neuroscience* 14.
- Dunbar, R.I.M. 2018. The Anatomy of Friendship. *Trends in Cognitive Sciences* 22(1): 32-51.
- Forster, P. 2010. Defining Life: The Virus Viewpoint. *Origins of Life and Evolution of Biospheres* 40(2): 151-160.
- Fortier, J. , Besnard, J. and Allain, P. 2018. Theory of mind, empathy and emotion perception in cortical and subcortical neurodegenerative diseases. *Revue Neurologique* 174(4): 237-246.
- Gerdes, H.-H. , Rustom, A. and Wang, X. 2013. Tunneling nanotubes, an emerging intercellular communication route in development. *Mechanisms of Development* 130(6-8): 381-387.
- Hanggi, P. 2002. Stochastic Resonance in Biology How Noise Can Enhance Detection of Weak Signals and Help Improve Biological Information Processing. *ChemPhysChem* 3(3): 285.
- Hegde, N.R. , Maddur, M.S. , Kaveri, S.V. and Bayry, J. 2009. Reasons to include viruses in the tree of life. *Nature Reviews Microbiology* 7(8): 615-615.
- Jose, A.M. 2018. Replicating and Cycling Stores of Information Perpetuate Life. *BioEssays* 40(4): 1700161.
- Kirchhoff, M. , Parr, T. , Palacios, E. , Friston, K. and Kiverstein, J. 2018. The Markov blankets of life: autonomy, active inference and the free energy principle. *Journal of The Royal Society Interface* 15(138): 20170792.
- Kováč, L. 2000. Fundamental principles of cognitive biology. pp. 51-69. *In: Evolution and Cognition*. Oxford, UK: Oxford University Press.
- Kováč, L. 2008. Bioenergetics-a key to brain and mind. *Communicative & Integrative Biology* 1(1): 114-122.
- Kühn, M.J. , Talà L. , Inclán, Y.F. , Patino, R. , Pierrat, X. , Vos, I. , Persat, A. 2021. Mechanotaxis directs *Pseudomonas aeruginosa* twitching motility. *Proceedings of the National Academy of Sciences* 118(30).
- Levin, M. 2021. Bioelectric signaling: Reprogrammable circuits underlying embryogenesis, regeneration, and cancer. *Cell* 184(8): 1971-1989.
- Levin, M. and Martyniuk, C.J. 2018. The bioelectric code: An ancient computational medium for dynamic control of growth and form. *Biosystems* 164: 76-93.
- Lintilhac, P.M. 1999. Toward a theory of cellularity Speculations on the nature of the living cell. *BioScience*.
- Loewenstein, W. 2013. *Physics in Mind: A Quantum View of the Brain*. New York: Basic Books.
- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).
- Marijuán, P.C. and Navarro, J. 2022. The biological information flow: From cell theory to a new evolutionary synthesis. *Biosystems* 213: 104631.

- Marijuán, P.C. , Navarro, J. and del Moral, R. 2015. How the living is in the world: An inquiry into the informational choreographies of life. *Progress in Biophysics and Molecular Biology* 119(3): 469-480.
- McDonnell, M.D. and Ward, L.M. 2011. The benefits of noise in neural systems: bridging theory and experiment. *Nature Reviews Neuroscience* 12(7): 415-425.
- Meyer, B. , Ansoorge, C. and Nakagaki, T. 2017. The role of noise in self-organized decision making by the true slime mold *Physarum polycephalum*. *Plos One* 12(3): e0172933.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Balugka, F. and Torday, J.S. 2020a. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Enguita, F.J. and Leitdo, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.
- Miller, W.B. and Torday, J.S. 2017. A systematic approach to cancer: evolution beyond selection. *Clinical and Translational Medicine* 6(2).
- Miller, W.B. and Torday, J. S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Miller, W.B. , Torday, J.S. and Balugka, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Minton, K. 2015. Apoptotic beads on a string. *Nature Reviews Molecular Cell Biology* 16(8): 453-453.
- Parkinson, C. , Kleinbaum, A.M. and Wheatley, T. 2018. Similar neural responses predict friendship. *Nature Communications* 9: 332.
- Ramstead, M.J.D. , Badcock, P.B. and Friston, K.J. 2018. Answering Schrodinger's question: A free-energy formulation. *Physics of Life Reviews* 24: 1-16.
- Ripamonti, M. , Liaudet, N. , Azizi, L. , Bouvard, D. , Hytonen, V.P. and Wehrle-Haller, B. 2021. Structural and functional analysis of LIM domain-dependent recruitment of paxillin to avl33 integrin-positive focal adhesions. *Communications Biology* 4: 380.
- Ruiz-Saenz, J. and Rodas, J. 2010. Viruses, virophages, and their living nature. *Acta Virologica* 54(2): 85-90.
- Schaden, G. and Patin, C. 2018. Semiotic systems with duality of patterning and the issue of cultural replicators. *History and Philosophy of the Life Sciences* 40(1): 4.
- Steringer, J.P. and Nickel, W. 2018. A direct gateway into the extracellular space: Unconventional secretion of FGF2 through self-sustained plasma membrane pores. *Seminars in Cell & Developmental Biology* 83: 3-7.
- Stock, J. and Levit, M. 2000. Signal transduction: Hair brains in bacterial chemotaxis. *Current Biology* 10(1): R11-R14.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology* Cham, Switzerland: Springer.
- Trosko, J.E. , Chang, C.-C. , Wilson, M.R. , Upham, B. , Hayashi, T. and Wade, M. 2000. Gap Junctions and the Regulation of Cellular Functions of Stem Cells during Development and Differentiation. *Methods* 20(2): 245-264.
- Vergassola, M., Villermaux, E. and Shraiman, B.I. 2007. 'Infotaxis' as a strategy for searching without gradients. *Nature* 445(7126): 406-409.
- Vitas, M. and Dobovišek, A. 2018. In the Beginning was a Mutualism—On the Origin of Translation. *Origins of Life and Evolution of Biospheres* 48(2): 223-243.
- Wittmann, M.K. , Lockwood, P.L. and Rushworth, M.F.S. 2018. Neural Mechanisms of Social Cognition in Primates. *Annual Review of Neuroscience* 41: 99-118.
- Witzany, G. 2016. The biocommunication method: On the road to an integrative biology. *Communicative & Integrative Biology* 9(2): e1164374.

## The N-space Episenome

- Affolter, M. and Basler, K. 2007. The Decapentaplegic morphogen gradient: from pattern formation to growth regulation. *Nature Reviews Genetics* 8(9): 663-674.
- Bahram, M. and Netherway, T. 2022. Fungi as mediators linking organisms and ecosystems. *FEMS Microbiology Reviews* 46(2).
- Baluška, F. and Miller, Jr., W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Baluška, F. and Reber, A. 2019. Sentience and Consciousness in Single Cells: How the First Minds Emerged in Unicellular Species. *BioEssays* 41(3): 1800229.
- Baverstock, K. 2013. The role of information in cell regulation. *Progress in Biophysics and Molecular Biology* 111(2-3): 141-143.
- Baverstock, K. 2021. The gene: An appraisal. *Progress in Biophysics and Molecular Biology* 164: 46-62.
- Bekenstein, J.D. 2003. Information in the Holographic Universe. *Scientific American* 289(2): 58-65.
- Blank, M. and Goodman, R. 2011. DNA is a fractal antenna in electromagnetic fields. *International Journal of Radiation Biology* 87(4): 409-415.
- Chapman, M.J. and Margulis, L. 1998. Morphogenesis by symbiogenesis. *International Microbiology: The Official Journal of the Spanish Society for Microbiology* 1(4): 319-326.
- Davies, P.C.W. and Walker, S.I. 2016. The hidden simplicity of biology. *Reports on Progress in Physics* 79(10): 102601.
- De la Fuente, I.M. 2021. Correspondence insights into the role of genes in cell functionality. Comments on "The gene: An appraisal" by K. Baverstock . *Progress in Biophysics and Molecular Biology* 167 152-160.
- De Loof, A. 2016. The cell's self-generated "electrome": The biophysical essence of the immaterial dimension of Life? *Communicative & Integrative Biology* 9(5): e1197446.
- Efron, B. 2013. Bayes' Theorem in the 21st Century. *Science* 340(6137): 1177-1178.
- Fels, D. 2018. The Double-Aspect of Life. *Biology* 7(2): 28.
- Fleury, V. and Gordon, R. 2012. Coupling of Growth, Differentiation and Morphogenesis: An Integrated Approach to Design in Embryogenesis. pp. 385-428. *In: Cellular Origin, Life in Extreme Habitats and Astrobiology Origin(s) of Design in Nature*. Netherlands: Springer.
- Friston, K. 2018. Am I Self-Conscious? (Or Does Self-Organization Entail Self-Consciousness?). *Frontiers in Psychology* 9.
- Friston, K. , Kilner, J. and Harrison, L. 2006. A free energy principle for the brain. *Journal of Physiology-Paris* 100(1-3): 70-87.
- Funk, R.H.W. 2015. Endogenous electric fields as guiding cue for cell migration. *Frontiers in Physiology* 6.
- Geesink, H.J.H. and Meijer, D.K.F. 2018. Mathematical Structure for Electromagnetic Frequencies that May Reflect Pilot Waves of Bohm's Implicate Order. *Journal of Modern Physics* 9(5): 851-897.
- Gilbert, S.F. 2019. Towards A Developmental Biology Of Holobionts. pp. 13-22. *In: G. Fusco (ed.). Perspectives On Evolutionary And Developmental Biology*. Padova: Padova University Press.
- Gilbert, S.F. and Sarkar, S. 2000. Embracing complexity: organicism for the 21st century. *Developmental Dynamics: An Official Publication of the American Association of Anatomists* 219(1): 1-9.
- Gurwitsch, A. 1912. *Biologisches Zentralblatt. Die Vererbung As Verwirklichungsvorgang* 32: 458-486.
- Huttenberger, S.M. and Mitteroecker, P. 2011. Invariance and Meaningfulness in Phenotype spaces. *Evolutionary Biology* 38(3): 335-351.
- Jiang, Y. , Kelly, R. , Peters, A. , Fulka, H. , Dickinson, A. , Mitchell, D.A. and St. John, J.C. 2011. Interspecies Somatic Cell Nuclear Transfer Is Dependent on Compatible Mitochondrial DNA and Reprogramming Factors. *PLoS ONE* 6(4): e14805.

Lagutina, I., Lazzari, G. and Galli, C. 2018.35 Interspecies Somatic Cell Nuclear Transfer Embryos that Form Nucleoli do not Always Activate Mitochondrial Functional Differentiation at the Time of Embryonic Genome Activation. *Reproduction, Fertility and Development* 30(1): 157.

Landauer, R. 2018. Information is inevitably physical. pp. 77-92. In: Feynman and computation. CRC Press.

Lev, L.L. , Maiboroda, I.O. , Husanu, M.-A. , Grichuk, E.S. , Chumakov, N.K. , Ezubchenko, I.S. , Strocov, V.N. 2018. k-space imaging of anisotropic 2D electron gas in GaN/GaAlN high-electronmobility transistor heterostructures. *Nature Communications* 9: 2653.

Levin, M. 2014. Endogenous bioelectrical networks store non-genetic patterning information during development and regeneration. *The Journal of Physiology* 592(11): 2295-2305.

Levin, M. 2021. Bioelectric signaling: Reprogrammable circuits underlying embryogenesis, regeneration, and cancer. *Cell* 184(8): 1971-1989.

Levin, M. and Martyniuk, C.J. 2018. The bioelectric code: An ancient computational medium for dynamic control of growth and form. *Biosystems* 164: 76-93.

Levin, M. , Pietak, A.M. and Bischof, J. 2019. Planarian regeneration as a model of anatomical homeostasis: Recent progress in biophysical and computational approaches. *Seminars in Cell & Developmental Biology* 87: 125-144.

Ildefonso, M. 2021. Correspondence insights into the role of genes in cell functionality. Comments on "The gene: An appraisal" by K. Baverstock . *Progress in Biophysics and Molecular Biology* 167: 152-160.

Mezrich, R. 1995. A perspective on K-space. *Radiology* 195(2): 297-315.

Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.

Miller, W.B. 2018. Biological Information Systems: Evolution as cognition-based Information Management. *Progress in Biophysics and Molecular Biology* 134: 1-26.

Miller, W.B. , Baluška, F. , Torday, J.S. 2020b. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.

Miller, W.B. , Enguita, F.J. and Leitdo, Al . 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.

Miller, W.B. , Torday, J.S. and Balugka, F. 2020a. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.

Moratal, D. , Valles-Luch, A. , Marti-Bonmati, L. and Brummer, M. 2008. k-Space tutorial: an MRI educational tool for a better understanding of k-space. *Biomedical Imaging and Intervention Journal* 4(1): e15.

Müller, P. and Schier, A.F. 2011. Extracellular Movement of Signaling Molecules. *Developmental Cell* 21(1): 145-158.

Neuhof, M. , Levin, M. and Rechavi, O. 2016. Vertically- and horizontally-transmitted memories the fading boundaries between regeneration and inheritance in planaria. *Biology Open* 5(9): 1177-1188.

Oreshkov, O. , Costa, F. and Brukner, Č . 2012. Quantum correlations with no causal order. *Nature Communications* 3: 1092.

Pai, V.P. , Lemire, J.M. , Pare, J.-F. , Lin, G. , Chen, Y. and Levin, M. 2015. Endogenous Gradients of Resting Potential Instructively Pattern Embryonic Neural Tissue via Notch Signaling and Regulation of Proliferation. *Journal of Neuroscience* 35(10): 4366-4385.

Pawlowski, M. , Paterek, T. , Kaszlikowski, D. , Scarani, V. , Winter, A. and Zukowski, M. 2009. Information causality as a physical principle. *Nature* 461(7267): 1101-1104.

Rafiq, K. , Cheers, M.S. and Ettensohn, C.A. 2012. The genomic regulatory control of skeletal morphogenesis in the sea urchin. *Development* 139(3): 579-590.

Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York, NY, USA: Oxford Press.

Rogers, K.W. and Schier, A.F. 2011. Morphogen Gradients: From Generation to Interpretation. *Annual Review of Cell and* 27: 377-407.

Roy, S. , Huang, H. , Liu, S. and Kornberg, T.B. 2014. Cytoneme-Mediated Contact-Dependent Transport of the *Drosophila* Decapentaplegic Signaling Protein. *Science* 343(6173).

Sepehri, A. 2017. A mathematical model for DNA. *International Journal of Geometric Methods in Modern* 1750152.

- Shapiro, J. 2017. Living Organisms Author Their Read-Write Genomes in Evolution. *Biology* 6(4): 42.
- Sullivan, K.G. , Emmons-Bell, M. and Levin, M. 2016. Physiological inputs regulate species-specific anatomy during embryogenesis and regeneration. *Communicative & Integrative Biology* 9(4): e1192733.
- Sun, Y.-H. and Zhu, Z.-Y. 2014. Cross-species cloning: influence of cytoplasmic factors on development. *The Journal of Physiology* 592(11): 2375-2379.
- Torday, J.S. and Miller, W.B. 2016. On the Evolution of the Mammalian Brain. *Frontiers in Systems Neuroscience* 10(31).
- Tzambazakis, A. 2015. The evolution of the biological field concept. pp. 1-27. *In*: D. Fels , M. Cifra and F. Scholkmann (eds.). *Fields of the Cell*. Kerala, India: Research Signpost.
- Villarreal L.P. and Ryan F. 2019. Viruses in the Origin of Life and Its Subsequent Diversification. *In Handbook of Astrobiology*. Boca Raton, Florida, United States: CRC Press.
- Walker, S.I. , Kim, H. and Davies, P.C.W. 2016. The informational architecture of the cell. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374(2063): 20150057.
- West, A.E. and Greenberg, M.E. 2011. Neuronal Activity-Regulated Gene Transcription in Synapse Development and Cognitive Function. *Cold Spring Harbor Perspectives in Biology* 3(6): a005744-a005744.
- Witzany, G. 2010. Biocommunicat on and natural genome editing. *World Journal of Biological Chemistry* 1(11): 348.
- Yamada, T. , Yang, Y. , Valnegri, P. , Juric, I. , Abnousi, A. , Markwalter, K.H. , Bonni, A. 2019. Sensory experience remodels genome architecture in neural circuit to drive motor learning. *Nature* 569(7758): 708-713.
- Yao, L. , Seaton, S.C. , Ndousse-Fetter, S. , Adhikari, A.A. , DiBenedetto, N. , Mina, A.I. , ... and Devlin, A.S. 2018. A selective gut bacterial bile salt hydrolase alters host metabolism. *Elife* 7.
- Zuo, Y. , Gao, Y. , Su, G. , Bai, C. , Wei, Z. , Liu, K. , ... Li, G. 2014. Irregular transcriptome reprogramming probably causes the developmental failure of embryos produced by interspecies somatic cell nuclear transfer between the Przewalski's gazelle and the bovine. *BMC Genomics* 15(1): 1113.

## Natural Cellular Engineering as Multicellular Problem-solving

- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology* 7.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Baluška, F. , Volkman, D. , Hlavacka, A. , Mancuso, S. and Barlow, P.W. 2006. Neurobiological View of Plants and Their Body Plan. pp. 19–35. *In*: *Communication in Plants*. Berlin, Heidelberg: Springer Berl in Heidelberg.
- Bellantuono, A.J. , Dougan, K.E. , Granados-Cifuentes, C. and Rodriguez-Lanetty, M. 2019. Freeliving and symbiotic lifestyles of a thermotolerant coral endosymbiont display profoundly distinct transcriptomes under both stable and heat stress conditions. *Molecular Ecology* 28(24): 5265–5281.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197–214.
- Bernardes, J.P. , John, U. , Woltermann, N. , Valiadi, M. , Hermann, R.J. and Becks, L. 2021. The evolution of convex trade-offs enables the transition towards multicellularity. *Nature Communications* 12: 4222.
- Bozdog, G.O. , Libby, E. , Pineau, R. , Reinhard, C.T. and Ratcliff, W.C. 2021. Oxygen suppression of macroscopic multicellularity. *Nature Communications* 12: 2838.
- Butterfield, N.J. 2018. Oxygen, animals and aquatic bioturbation: An updated account. *Geobiology* 16(1): 3–16.
- Chipman, A.D. 2021. Developmental Exaptation. pp. 29–38. *In*: L.N. de la Rosa and G.B. Müller (eds.). *Evolutionary Developmental Biology*. Springer Cham.

- Chou, K.-T. , Lee, D.D. , Chiou, J. , Galera-Laporta, L. , Ly, S. , Garcia-Ojalvo, J. and Süel, G.M. 2022. A segmentation clock patterns cellular differentiation in a bacterial biofilm. *Cell* 185(1): 145–157.e13.
- Cooper, G.A. and West, S.A. 2018. Division of labour and the evolution of extreme specialization. *Nature Ecology & Evolution* 2(7): 1161–1167.
- De Loof, A. 2015a. From Darwin's On the Origin of Species by Means of Natural Selection... to The evolution of Life with Communication Activity as its Very Essence and Driving Force (= Mega-Evolution). *Life: The Excitement of Biology* 3(3): 153–187.
- De Loof, A. 2015b. How to deduce and teach the logical and unambiguous answer, namely  $L = \Sigma C$ , to "What is Life?" using the principles of communication? *Communicative & Integrative Biology* 8(5): e1059977.
- Dexter, J.P. , Prabakaran, S. and Gunawardena, J. 2019. A Complex Hierarchy of Avoidance Behaviors in a Single-Cell Eukaryote. *Current Biology* 29(24): 4323–4329.e2.
- Heylighen, F. 2001. The science of self-organization and adaptivity. *The Encyclopedia of Life Support Systems* 5(3): 253–280.
- Heylighen, F. 2015. Stigmergy as a Universal Coordination Mechanism: Components, varieties and Applications. Lewis, T. and Marsh, L. (eds.). In: *Human Stigmergy: Theoretical Developments and New Applications*. New York, Springer.
- Kanso, E.A. , Lopes, R.M. , Strickler, J.R. , Dabiri, J.O. and Costello, J.H. 2021. Teamwork in the viscous oceanic microscale. *Proceedings of the National Academy of Sciences* 118(29).
- Laland, K.N. , Sterelny, K. , Odling-Smee, J. , Hoppitt, W. and Uller, T. 2011. Cause and Effect in Biology Revisited: Is Mayr's Proximate-Ultimate Dichotomy Still Useful? *Science* 334(6062): 1512–1516.
- Larkin, J.W. , Zhai, X. , Kikuchi, K. , Redford, S.E. , Prindle, A. , Liu, J. , ... Süel, G.M. 2018. Signal Percolation within a Bacterial Community. *Cell Systems* 7(2): 137–145.e3.
- Levin, T.C. , Greaney, A.J. , Wetzel, L. and King, N. 2014. The rosetteless gene controls development in the choanoflagellate *S. rosetta*. *ELife* 3.
- Libby, E. and Ratcliff, W.C. 2014. Ratcheting the evolution of multicellularity. *Science* 346(6208): 426–427.
- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6.
- McClintock, B. 1984. The Significance of Responses of the Genome to Challenge. *Science* 226(4676): 792–801.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological Information Systems: Evolution as cognition-based Information Management. *Progress in Biophysics and Molecular Biology* 134: 1–26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.
- Miller, W.B. , Enguita, F.J. and Leitão, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.
- Miller, W.B. and Torday, J.S. 2017. A systematic approach to cancer: evolution beyond selection. *Clinical and Translational Medicine* 6(2).
- Miller, Jr., W.B. and Torday, J.S. 2019. Reappraising the exteriorization of the mammalian testes through evolutionary physiology. *Communicative & Integrative Biology* 12(1): 38–54.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54–74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.
- Minakawa, T. , Matoba, T. , Ishidate, F. , Fujiwara, T.K. , Takehana, S. , Tabata, Y. and Yamashita, J.K. 2021. Extracellular vesicles synchronize cellular phenotypes of differentiating cells. *Journal of Extracellular Vesicles* 10(11).
- Nutman, A.P. , Bennett, V.C. , Friend, C.R.L. , Van Kranendonk, M.J. , Rothacker, L. and Chivas, A.R. 2019. Cross-examining Earth's oldest stromatolites: Seeing through the effects of heterogeneous deformation, metamorphism and metasomatism affecting Isua (Greenland) ≈ 3700 Ma sedimentary rocks. *Precambrian Research* 331: 105347.
- Odling-Smee, F.J. , Laland, K.N. and Feldman, M.W. 2003. *Niche Construction: The Neglected Process in Evolution*. Princeton, New Jersey: Princeton University Press.

Oliver, K.R. and Greene, W.K. 2009. Transposable elements: powerful facilitators of evolution. *BioEssays* 31(7): 703–714.

Papineau, D. , She, Z. , Dodd, M.S. , Iacoviello, F. , Slack, J.F. , Hauri, E. , ... Little, C.T.S. 2022. Metabolically diverse primordial microbial communities in Earth's oldest seafloor-hydrothermal jasper. *Science Advances* 8(15).

Picard, M. and Sandi, C. 2021. The social nature of mitochondria: Implications for human health. *Neuroscience & Biobehavioral Reviews* 120: 595–610.

Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York, NY, USA: Oxford University Press.

Reber, A.S. and Baluška, F. 2021. Cognition in some surprising places. *Biochemical and Biophysical Research Communications* 564: 150–157.

Rooney, L.M. , Amos, W.B. , Hoskisson, P.A. and McConnell, G. 2020. Intra-colony channels in *E. coli* function as a nutrient uptake system. *The ISME Journal* 14(10): 2461–2473.

Schlesinger, S. and Goff, S.P. 2015. Retroviral Transcriptional Regulation and Embryonic Stem Cells: War and Peace. *Molecular and Cellular Biology* 35(5): 770–777.

Schrader, L. , Kim, J.W. , Ence, D. , Zimin, A. , Klein, A. , Wyschetzki, K. , ... Oettler J. 2014. Transposable element islands facilitate adaptation to novel environments in an invasive species. *Nature Communications* 5: 5495.

Sebé-Pedrós, A. , Ballaré, C. , Parra-Acero, H. , Chiva, C. , Tena, J.J. , Sabidó, E. , ... Ruiz-Trillo, I. 2016. The Dynamic Regulatory Genome of *Capsaspora* and the Origin of Animal Multicellularity. *Cell* 165(5): 1224–1237.

Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.

Shapiro, J.A. 2017. Exploring the read-write genome: mobile DNA and mammalian adaptation. *Critical Reviews in Biochemistry and Molecular Biology* 52(1): 1–17.

Shapiro, J.A. 2021. All living cells are cognitive. *Biochemical and Biophysical Research Communications* 564: 134–149.

Torday, J. 2016. The Cell as the First Niche Construction. *Biology* 5(2): 19.

Torday, J. and Miller, W. 2016. Phenotype as Agent for Epigenetic Inheritance. *Biology* 5(3): 30.

Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.

Trewavas, A.J. and Baluška, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221–1225.

Vallverdú, J. , Castro, O. , Mayne, R. , Talanov, M. , Levin, M. , Baluška, F. , ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57–70.

Witzany, G. 2010. Biocommunication and natural genome editing. *World Journal of Biological Chemistry* 1(11): 348.

Witzany, G. 2011. The agents of natural genome editing. *Journal of Molecular Cell Biology* 3(3): 181–189.

Yang, C.-Y. , Bialecka-Fornal, M. , Weatherwax, C. , Larkin, J.W. , Prindle, A. , Liu, J. , ... Süel G.M. . 2020. Encoding Membrane-Potential-Based Memory within a Microbial Community. *Cell Systems* 10(5): 417–423.e3.

## Non-random Variations in Natural Cellular Engineering

Ambrosi, A. , Cattoglio, C. and Di Serio, C. 2008. Retroviral Integration Process in the Human Genome: Is It Really Non-Random? A New Statistical Approach. *PLoS Computational Biology* 4(8): e1000144.

Archibald, J.M. 2015. Endosymbiosis and Eukaryotic Cell Evolution. *Current Biology* 25(19): R911–R921.

Arkipova, I.R. and Yushenova, I.A. 2019. Giant Transposons in Eukaryotes: Is Bigger Better? *Genome Biology and Evolution* 11(3): 906–918.

Asfahl, K.L. and Schuster, M. 2017. Social interactions in bacterial cell–cell signaling. *FEMS Microbiology Reviews* 41(1): 92–107.

- Ball, P. 2016. The problems of biological information. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*: 374(2063) 20150072.
- Black, S.G. , Arnaud, F. , Palmarini, M. and Spencer, T.E. 2010. Endogenous Retroviruses in Trophoblast Differentiation and Placental Development. *American Journal of Reproductive Immunology* 64(4): 255–264.
- Bourque, G. , Burns, K.H. , Gehring, M. , Gorbunova, V. , Seluanov, A. , Hammell, M. , ... Feschotte, C. . 2018. Ten things you should know about transposable elements. *Genome Biology* 19: 199.
- Broecker, F. and Moelling, K. 2019. Evolution of Immune Systems From Viruses and Transposable Elements. *Frontiers in Microbiology* 10.
- Brown, C.J. and Rupert, J.L. 2014. Hypoxia and Environmental Epigenetics. *High Altitude Medicine & Biology* 15(3): 323–330.
- Chain, E.B. 1971. Social Responsibility and the Scientist in Modern Western Society. *Perspectives in Biology and Medicine* 14(3): 347–369.
- Ecco, G. , Imbeault, M. and Trono, D. 2017. KRAB zinc finger proteins. *Development* 144(15):2719–2729.
- Enard, D. , Cai, L. , Gwennap, C. and Petrov, D.A. 2016. Viruses are a dominant driver of protein adaptation in mammals. *ELife* 5.
- Feschotte, C. and Gilbert, C. 2012. Endogenous viruses: insights into viral evolution and impact on host biology. *Nature Reviews Genetics* 13(4): 283–296.
- Gilbert, C. and Cordaux, R. 2017. Viruses as vectors of horizontal transfer of genetic material in eukaryotes. *Current Opinion in Virology* 25: 16–22.
- Goldenfeld, N. and Woese, C. 2011. Life is Physics: Evolution as a Collective Phenomenon Far From Equilibrium. *Annual Review of Condensed Matter Physics* 2(1): 375–399.
- Guex, J. 2020. The Controversial Cope's, Haeckel's and Dollo's Evolutionary Rules: The Role of Evolutionary Retrogradation. pp. 13–22. In: *Morphogenesis, Environmental Stress and Reverse Evolution*. Cham: Springer International Publishing.
- Habig, M. , Lorrain, C. , Feurtey, A. , Komlusi, J. and Stukenbrock, E.H. 2021. Epigenetic modifications affect the rate of spontaneous mutations in a pathogenic fungus. *Nature Communications* 12: 5869.
- Jangam, D. , Feschotte, C. and Betrán, E. 2017. Transposable Element Domestication As an Adaptation to Evolutionary Conflicts. *Trends in Genetics* 33(11): 817–831.
- Janssen, A. and Medema, R.H. 2011. Entosis: aneuploidy by invasion. *Nature Cell Biology* 13(3): 199–201.
- Jobson, M.A. , Jordan, J.M. , Sandrof, M.A. , Hibshman, J.D. , Lennox, A.L. and Baugh, L.R. 2015. Transgenerational Effects of Early Life Starvation on Growth, Reproduction, and Stress Resistance in *Caenorhabditis elegans*. *Genetics* 201(1): 201–212.
- Kiliç, A.M. , Plasencia, P. , Ishida, K. , Guex, J. and Hirsch, F. 2016. Proteromorphosis of Neospathodus (Conodonts) during the Permian–Triassic crisis and recovery. *Revue de Micropaléontologie* 59(1): 33–39.
- Koonin, E.V. 2009. Darwinian evolution in the light of genomics. *Nucleic Acids Research* 37(4): 1011–1034.
- Lacroix, B. and Citovsky, V. 2019. Pathways of DNA Transfer to Plants from *Agrobacterium tumefaciens* and Related Bacterial Species. *Annual Review of Phytopathology* 57: 231–251.
- Laland, K. , Uller, T. , Feldman, M. , Sterelny, K. , Müller, G.B. , Moczek, A. , ... Strassmann, J.E. 2014. Does evolutionary theory need a rethink? *Nature* 514(7521): 161–164.
- Lupo, A. , Cesaro, E. , Montano, G. , Zurlo, D. , Izzo, P. and Costanzo, P. 2013. KRAB-Zinc Finger Proteins: A Repressor Family Displaying Multiple Biological Functions. *Current Genomics* 14(4): 268–278.
- Ma, J. , Wang, S. , Zhu, X. , Sun, G. , Chang, G. , Li, L. , ... Huang, J. 2022. Major episodes of horizontal gene transfer drove the evolution of land plants. *Molecular Plant* 15(5): 857–871.
- Martin, W.F. , Garg, S. and Zimorski, V. 2015. Endosymbiotic theories for eukaryote origin. *Philosophical Transactions of the Royal Society B: Biological Sciences* 370(1678): 20140330.
- Martinez, G. , Castellano, M. , Tortosa, M. , Pallas, V. and Gomez, G. 2014. A pathogenic non-coding RNA induces changes in dynamic DNA methylation of ribosomal RNA genes in host plants. *Nucleic Acids Research* 42(3): 1553–1562.
- Martinez, J. , Klasson, L. , Welch, J.J. and Jiggins, F.M. 2021. Life and Death of Selfish Genes: Comparative Genomics Reveals the Dynamic Evolution of Cytoplasmic Incompatibility.

Molecular Biology and Evolution 38(1): 2–15.

Matveeva, T.V. and Otten, L. 2019. Widespread occurrence of natural genetic transformation of plants by *Agrobacterium*. *Plant Molecular Biology* 101(4–5): 415–437.

Melamed, D. , Nov, Y. , Malik, A. , Yakass, M.B. , Bolotin, E. , Shemer, R. , ... Livnat, A. 2022. De novo mutation rates at the single-mutation resolution in a human HBB gene region associated with adaptation and genetic disease. *Genome Research* 32(3): 488–498.

Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.

Miller, W.B. 2018. Biological Information Systems: Evolution as cognition-based Information Management. *Progress in Biophysics and Molecular Biology* 134: 1–26.

Miller, W.B. , Baluška, F. and Torday, J.S. 2020b. Cellular genomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.

Miller, W.B. , Enguita, F.J. and Leitão, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.

Miller, W.B.J. , Reber, A.S. , Marshall, P. and Baluška, F. 2022. Viral-Cellular Natural Engineering in Cognition-Based Evolution. *Communicative & Integrative Biology*. Accepted in press.

Miller, Jr, W.B. and Torday, J.S. 2019. Reappraising the exteriorization of the mammalian testes through evolutionary physiology. *Communicative & Integrative Biology* 12(1): 38–54.

Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of “self”. *Progress in Biophysics and Molecular Biology* 142: 54–74.

Miller, W.B. , Torday, J.S. and Baluška, F. 2020a. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.

Milstein, J.N. and Meiners, J.-C. 2011. On the role of DNA biomechanics in the regulation of gene expression. *Journal of The Royal Society Interface* 8(65): 1673–1681.

Monroe, J.G. , Srikant, T. , Carbonell-Bejerano, P. , Becker, C. , Lensink, M. , Exposito-Alonso, M. , ... Weigel, D. . 2022. Mutation bias reflects natural selection in *Arabidopsis thaliana*. *Nature* 602(7895): 101–105.

Mustafin, R.N. 2018. Hypothesis on the Origin of Viruses from Transposons. *Molecular Genetics, Microbiology and Virology* 33(4): 223–232.

Muszewska, A. , Steczkiewicz, K. , Stepniewska-Dziubinska, M. and Ginalski, K. 2019. Transposable elements contribute to fungal genes and impact fungal lifestyle. *Scientific Reports* 9: 4307.

Noble, D. 2018. Central Dogma or Central Debate? *Physiology* 33(4): 246–249.

Overholtzer, M. , Mailloux, A.A. , Mouneimne, G. , Normand, G. , Schnitt, S.J. , King, R.W. , ... Brugge, J. S. 2007. A Nonapoptotic Cell Death Process, Entosis, that Occurs by Cell-in-Cell Invasion. *Cell* 131(5): 966–979.

Palmer, W.H. , Hadfield, J.D. and Obbard, D.J. 2018. RNA-Interference Pathways Display High Rates of Adaptive Protein Evolution in Multiple Invertebrates. *Genetics* 208(4): 1585–1599.

Paulsen, T. , Shibata, Y. , Kumar, P. , Dillon, L. and Dutta, A. 2019. Small extrachromosomal circular DNAs, microDNA, produce short regulatory RNAs that suppress gene expression independent of canonical promoters. *Nucleic Acids Research* 47(9): 4586–4596.

Petryk, N. , Dalby, M. , Wenger, A. , Stromme, C.B. , Strandsby, A. , Andersson, R. and Groth, A. 2018. MCM2 promotes symmetric inheritance of modified histones during DNA replication. *Science* 361(6409): 1389–1392.

Popat, R. , Cornforth, D.M. , McNally, L. and Brown, S.P. 2015. Collective sensing and collective responses in quorum-sensing bacteria. *Journal of The Royal Society Interface* 12(103): 20140882.

Popov, M. , Kolotova, T. and Davidenko, M. 2018. Endogenous Retroviruses as Genetic Modules that Shape the Genome Regulatory Networks During Evolution. *Journal of V.N. Karazin Kharkiv National University, Series “Medicine”* 36: 80–95.

Roberts, R.M. , Ezashi, T. , Schulz, L.C. , Sugimoto, J. , Schust, D.J. , Khan, T. and Zhou, J. 2021. Syncytins expressed in human placental trophoblast. *Placenta* 113: 8–14.

Rook, G. , Bäckhed, F. , Levin, B.R. , McFall-Ngai, M.J. and McLean, A.R. 2017. Evolution, human-microbe interactions, and life history plasticity. *The Lancet* 390(10093): 521–530.

Rudkin, D.M. and Young, G.A. 2009. Horseshoe Crabs—An Ancient Ancestry Revealed. pp. 25–44. In: *Biology and Conservation of Horseshoe Crabs*. Boston, MA: Springer.

- Ryan, F. 2009. *Viroolution*. New York, NY, USA: HarperCollins Publishers.
- Schmitz, M. , Driesch, C. , Jansen, L. , Runnebaum, I.B. and Dürst, M. 2012. Non-Random Integration of the HPV Genome in Cervical Cancer. *PLoS ONE* 7(6): e39632.
- Shapiro, J.A. 2013. How life changes itself: The Read–Write (RW) genome. *Physics of Life Reviews* 10(3): 287–323.
- Shapiro, J. 2016a. Nothing in Evolution Makes Sense Except in the Light of Genomics: Read–Write Genome Evolution as an Active Biological Process. *Biology* 5(2): 27.
- Shapiro, J.A. 2016b. The basic concept of the read–write genome: Mini-review on cell-mediated DNA modification. *Biosystems* 140: 35–37.
- Shapiro, J.A. 2017. Living Organisms Author Their Read-Write Genomes in Evolution. *Biology* 6(4): 42.
- Shapiro, J.A. 2019. No genome is an island: toward a 21st century agenda for evolution. *Annals of the New York Academy of Sciences* 1447: 21–52.
- Shapiro, J.A. 2022. What we have learned about evolutionary genome change in the past 7 decades. *Biosystems* 215–216: 104669.
- Shorter, J. and Lindquist, S. 2005. Prions as adaptive conduits of memory and inheritance. *Nature Reviews Genetics* 6(6): 435–450.
- Skinner, M.K. 2014. Environmental stress and epigenetic transgenerational inheritance. *BMC Medicine* 12(1): 153.
- Smalheiser, N.R. 2014. The RNA-centred view of the synapse: non-coding RNAs and synaptic plasticity. *Philosophical Transactions of the Royal Society B: Biological Sciences* 369(1652): 20130504.
- Sobhy, H. 2017. A comparative review of viral entry and attachment during large and giant dsDNA virus infections. *Archives of Virology* 162(12): 3567–3585.
- Soucy, S.M. , Huang, J. and Gogarten, J.P. 2015. Horizontal gene transfer: building the web of life. *Nature Reviews Genetics* 16(8): 472–482.
- Stegemann, R. and Buchner, D.A. 2015. Transgenerational inheritance of metabolic disease. *Seminars in Cell & Developmental Biology* 43: 131–140.
- Stockdale, M.T. and Benton, M.J. 2021. Environmental drivers of body size evolution in crocodile-line archosaurs. *Communications Biology* 4: 38.
- Sultana, T. , Zamborlini, A. , Cristofari, G. and Lesage, P. 2017. Integration site selection by retroviruses and transposable elements in eukaryotes. *Nature Reviews Genetics* 18(5): 292–308.
- Torday, J. and Miller, W. 2020a. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Torday, J.S. and Miller, W.B.Jr . 2020b. Evolution as a timeless continuum. In: J. Guex , J.S. Torday and W.B.J. Miller (eds.). *Morphogenesis, Environmental Stress and Reverse Evolution*. Cham, Switzerland: Springer.
- Villarreal, L.P. and Ryan, F. 2019. Viruses in the Origin of Life and Its Subsequent Diversification. In: V.M. Kolb (ed.). *Handbook of Astrobiology*. Boca Raton, Florida, United States: CRC Press.
- Villarreal, L.P. and Witzany, G. 2018. Editorial: Genome Invading RNA Networks. *Frontiers in Microbiology* 9(581).
- Villarreal, L.P. and Witzany, G. 2019. That is life: communicating RNA networks from viruses and cells in continuous interaction. *Annals of the New York Academy of Sciences* 1447: 5–20.
- Vogel, D. and Dussutour, A. 2016. Direct transfer of learned behaviour via cell fusion in non-neural organisms. *Proceedings of the Royal Society B: Biological Sciences* 283(1845): 20162382.
- Wallau, G.L. , Vieira, C. and Loreto, É.L.S. 2018. Genetic exchange in eukaryotes through horizontal transfer: connected by the mobilome. *Mobile DNA* 9: 6.
- Waszak, S.M. , Delaneau, O. , Gschwind, A.R. , Kilpinen, H. , Raghav, S.K. , Witwicki, R.M. , ... Dermizakis, E.T. 2015. Population Variation and Genetic Control of Modular Chromatin Architecture in Humans. *Cell* 162(5): 1039–1050.
- Wei, B. , Liu, H. , Liu, X. , Xiao, Q. , Wang, Y. , Zhang, J. , ... Huang, Y. 2016. Genome-wide characterization of non-reference transposons in crops suggests non-random insertion. *BMC Genomics* 17: 536.
- Wellenreuther, M. , Mérot, C. , Berdan, E. and Bernatchez, L. 2019. Going beyond SNPs: The role of structural genomic variants in adaptive evolution and species diversification. *Molecular*

Ecology 28(6): 1203–1209.

Whitesides, G. 2004. The improbability of life Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning vol xiii, ed J.D. Barrow et al. Cambridge: Cambridge University Press.

Wilke, C.O. and Sawyer, S.L. 2016. At the mercy of viruses. *ELife*, 5.

Witzany, G. 2011. Natural Genome Editing from a Biocommunicative Perspective. *Biosemitotics* 4(3): 349–368.

Witzany, G. 2014. RNA Sociology: Group Behavioral Motifs of RNA Consortia. *Life* 4(4): 800–818.

Witzany, G. 2020. Evolution of Genetic Information without Error Replication. pp. 295–320. In: *Theoretical Information Studies: Volume 11. World Scientific Series in Information Studies.*

Zamai, L. 2020. Unveiling Human Non-Random Genome Editing Mechanisms Activated in Response to Chronic Environmental Changes: I. Where Might These Mechanisms Come from and What Might They Have Led To? *Cells* 9(11): 2362.

## The Virome and Natural Viral-Cellular Engineering

Aanen, D.K. and Eggleton, P. 2017. Symbiogenesis: Beyond the endosymbiosis theory? *Journal of Theoretical Biology* 434: 99–103.

Abedon, S.T. 2020. Phage-Phage, Phage-Bacteria, and Phage-Environment Communication. pp. 23–70. In: *Biocommunication of Phages.* Cham: Springer International Publishing.

Adachi, A. 2020. Grand Challenge in Human/Animal Virology: Unseen, Smallest Replicative Entities Shape the Whole Globe. *Frontiers in Microbiology* 11.

Alvisi, G. 2013. Reprogramming the host: Modification of cell functions upon viral infection. *World Journal of Virology* 2(2): 16.

Bândeă, C.I. 1983. A new theory on the origin and the nature of viruses. *Journal of Theoretical Biology* 105(4): 591–602.

Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178: 106–119.

Cheng, S. , Wong, G.K.-S. and Melkonian, M. 2021. Giant DNA viruses make big strides in eukaryote evolution. *Cell Host & Microbe* 29(2): 152–154.

Chuong, E.B. 2013. Retroviruses facilitate the rapid evolution of the mammalian placenta. *BioEssays* 35(10): 853–861.

Claverie, J.-M. 2006. Viruses take center stage in cellular evolution. *Genome Biology* 7(6): 110.

Claverie, J.-M. and Abergel, C. 2016. Giant viruses: The difficult breaking of multiple epistemological barriers. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 59: 89–99.

Clokie, M.R.J. , Millard, A.D. , Letarov, A.V. and Heaphy, S. 2011. Phages in nature. *Bacteriophage* 1(1): 31–45.

Cosby, R.L. , Judd, J. , Zhang, R. , Zhong, A. , Garry, N. , Pritham, E.J. and Feschotte, C. 2021. Recurrent evolution of vertebrate transcription factors by transposase capture. *Science* 371(6531): eabc6405.

de Castro, I.F. , Volonté, L. and Risco, C. 2013. Virus factories: biogenesis and structural design. *Cellular Microbiology* 15(1): 24–34.

den Boon, J.A. , Diaz, A. and Ahlquist, P. 2010. Cytoplasmic Viral Replication Complexes. *Cell Host & Microbe* 8(1): 77–85.

Díaz-Muñoz, S.L. , Sanjuán, R. and West, S. 2017. Sociovirology: Conflict, Cooperation, and Communication among Viruses. *Cell Host & Microbe* 22(4): 437–441.

Dinsdale, E.A. , Edwards, R.A. , Hall, D. , Angly, F. , Breitbart, M. , Brulc, J.M. , ... Rohwer, F. 2008. Functional metagenomic profiling of nine biomes. *Nature* 452(7187): 629–632.

Dolgin, E. 2019. The secret social lives of viruses. *Nature* 570(7761): 290–292.

Domingo-Calap, P. , Segredo-Otero, E. , Durán-Moreno, M. and Sanjuán, R. 2019. Social evolution of innate immunity evasion in a virus. *Nature Microbiology* 4(6): 1006–1013.

Domingo, E. and Perales, C. 2019. Viral quasispecies. *PLOS Genetics* 15(10): e1008271.

Endo, H. , Blanc-Mathieu, R. , Li, Y. , Salazar, G. , Henry, N. , Labadie, K. , ... Ogata, H. 2020. Biogeography of marine giant viruses reveals their interplay with eukaryotes and ecological

functions. *Nature Ecology & Evolution* 4(12): 1639–1649.

Erez, Z. , Steinberger-Levy, I. , Shamir, M. , Doron, S. , Stokar-Avihail, A. , Peleg, Y. , ... Sorek, R. 2017. Communication between viruses guides lysis–lysogeny decisions. *Nature* 541(7638): 488–493.

Fischer, M.G. 2016. Giant viruses come of age. *Current Opinion in Microbiology* 31: 50–57.

Forterre, P. 2013. The virocell concept and environmental microbiology. *The ISME Journal* 7(2): 233–236.

Forterre, P. 2016. To be or not to be alive: How recent discoveries challenge the traditional definitions of viruses and life. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 59: 100–108.

Forterre, P. 2017. The Origin, Nature and Definition of Viruses (and Life): New Concepts and Controversies. pp. 15–26. In: P.J. Heidt , P.L. Ogra , M.S. Riddle and V. Rusch (eds.). *Old Herborn University Seminar Monograph 31: Evolutionary Biology of The Virome, and Impacts In Human Health and Disease*. Old Herborn University.

Forterre, P. and Prangishvili, D. 2009. The Great Billion-year War between Ribosome- and Capsid-encoding Organisms (Cells and Viruses) as the Major Source of Evolutionary Novelities. *Annals of the New York Academy of Sciences*, 1178: 65–77.

Holmfeldt, K. , Nilsson, E. , Simone, D. , Lopez-Fernandez, M. , Wu, X. , de Bruijn, I. , ... Dopson, M. 2021. The Fennoscandian Shield deep terrestrial virosphere suggests slow motion 'boom and burst' cycles. *Communications Biology* 4(1): 307.

Koonin, E.V. 2016. Viruses and mobile elements as drivers of evolutionary transitions. *Philosophical Transactions of the Royal Society B: Biological Sciences* 371(1701): 20150442.

Koonin, E.V. and Wolf, Y.I. 2012. Evolution of microbes and viruses: a paradigm shift in evolutionary biology? *Frontiers in Cellular and Infection Microbiology* 2(119).

Koonin, E.V. and Krupovic, M. 2017. Polintons, virophages and transpovirons: a tangled web linking viruses, transposons and immunity. *Current Opinion in Virology* 25: 7–15.

Leeks, A. , Sanjuán, R. and West, S.A. 2019. The evolution of collective infectious units in viruses. *Virus Research* 265: 94–101.

Liu, K. and Hu, J. 2019. Secretion of empty or complete hepatitis B virions: envelopment of empty capsids versus mature nucleocapsids. *Future Virology* 14(2): 95–105.

Malik, S.S. , Azem-e-Zahra, S. , Kim, K.M. , Caetano-Anollés, G. and Nasir, A. 2017. Do Viruses Exchange Genes across Superkingdoms of Life? *Frontiers in Microbiology* 8.

Margolis, L. and Sadovsky, Y. 2019. The biology of extracellular vesicles: The known unknowns. *PLOS Biology* 17(7): e3000363.

Marijuán, P.C. and Navarro, J. 2022. The biological information flow: From cell theory to a new evolutionary synthesis. *Biosystems* 213: 104631.

Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.

Miller, W.B. 2016. *Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow*. *Biology* 5(2): 21.

Miller, W.B. , Enguita, F.J. and Leitão, A.L. 2021. Non-Random Genome Editing and Natural Cellular Engineering in Cognition-Based Evolution. *Cells* 10(5): 1125.

Miller, W.B. , Reber, A.S. , Marshall, P. and Baluška, F. 2022. *Viral-Cellular Natural Engineering in Cognition-Based Evolution. Communicative and Integrative Biology*, Accepted in Press.

Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.

Mirzaei, K.M. , Xue, J. , Costa, R. , Ru, J. , Schulz, S. , Taranu, Z.E. and Deng, L. 2021. Challenges of Studying the Human Virome—Relevant Emerging Technologies. *Trends in Microbiology* 29(2): 171–181.

Mizuno, C.M. , Guyomar, C. , Roux, S. , Lavigne, R. , Rodriguez-Valera, F. , Sullivan, M.B. , ... Krupovic, M. 2019. Numerous cultivated and uncultivated viruses encode ribosomal proteins. *Nature Communications* 10(1): 752.

Mohsen, M. , Gomes, A. , Vogel, M. and Bachmann, M. 2018. Interaction of Viral Capsid-Derived Virus-Like Particles (VLPs) with the Innate Immune System. *Vaccines* 6(3): 37.

Moniruzzaman, M. , Martinez-Gutierrez, C.A. , Weinheimer, A.R. and Aylward, F.O. 2020. Dynamic genome evolution and complex virocell metabolism of globally-distributed giant viruses. *Nature Communications* 11: 1710.

- Moniruzzaman, M. , Weinheimer, A.R. , Martinez-Gutierrez, C.A. and Aylward, F.O. 2020. Widespread endogenization of giant viruses shapes genomes of green algae. *Nature* 588(7836): 141–145.
- Nasir, A. and Caetano-Anollés, G. 2015. A phylogenomic data-driven exploration of viral origins and evolution. *Science Advances* 1(8): e1500527.
- Netherton, C.L. and Wileman, T. 2011. Virus factories, double membrane vesicles and viroplasm generated in animal cells. *Current Opinion in Virology* 1(5): 381–387.
- Niehl, A. , Peña, E.J. , Amari, K. and Heinlein, M. 2013. Microtubules in viral replication and transport. *The Plant Journal* 75(2): 290–308.
- Noble, D. 2020. Exosomes, gemmules, pangenes and Darwin. pp. 487–501. In: L. Edelstein , J. Smythies , P. Quesenberry and D. Noble (eds.). *Exosomes: A Clinical Compendium*. Cambridge, Massachusetts: Academic Press.
- Nolte-t Hoen, E. , Cremer, T. , Gallo, R.C. and Margolis, L.B. 2016. Extracellular vesicles and viruses: Are they close relatives? *Proceedings of the National Academy of Sciences* 113(33): 9155–9161.
- Novoa, R.R. , Calderita, G. , Arranz, R. , Fontana, J. , Granzow, H. and Risco, C. 2005. Virus factories: associations of cell organelles for viral replication and morphogenesis. *Biology of the Cell* 97(2): 147–172.
- Ofir, G. and Sorek, R. 2018. Contemporary Phage Biology: From Classic Models to New Insights. *Cell* 172(6): 1260–1270.
- Patton, J.T. , Silvestri, L.S. , Tortorici, M.A. , Vasquez-Del Carpio, R. and Taraporewala, Z.F. 2006. Rotavirus Genome Replication and Morphogenesis: Role of the Viroplasm. pp. 169–187. In: *Reoviruses: Entry, Assembly and Morphogenesis*. Springer Berl in Heidelberg.
- Rohwer, F. and Thurber, R.V. 2009. Viruses manipulate the marine environment. *Nature* 459(7244): 207–212.
- Roossinck, M.J. 2008. Symbiosis, Mutualism and Symbiogenesis. pp. 157–164. In: *Plant Virus Evolution*. Berlin, Heidelberg: Springer.
- Roossinck, M.J. and Bazán, E.R. 2017. Symbiosis: Viruses as Intimate Partners. *Annual Review of Virology* 4: 123–139.
- Ryan, F. 2009. *Virovolution*. New York, NY, USA: HarperCollins Publishers.
- Ryan, F. 2019. *Virusphere: From common colds to Ebola epidemics—why we need the viruses that plague us*. HarperCollins UK.
- Ryan, F.P. 2016. Viral symbiosis and the holobiontic nature of the human genome. *Apmis* 124(1–2): 11–19.
- Sanjuán, R. 2017. Collective Infectious Units in Viruses. *Trends in Microbiology* 25(5): 402–412.
- Sanjuán, R. and Thoulouze, M.-I. 2019. Why viruses sometimes disperse in groups†. *Virus Evolution* 5(1): vez014.
- Schoelz, J.E. and Leisner, S. 2017. Setting Up Shop: The Formation and Function of the Viral Factories of Cauliflower mosaic virus. *Frontiers in Plant Science* 8(1832).
- Serganov, A. and Patel, D.J. 2007. Ribozymes, riboswitches and beyond: regulation of gene expression without proteins. *Nature Reviews Genetics* 8(10): 776–790.
- Shapiro, J. 2016. Nothing in Evolution Makes Sense Except in the Light of Genomics: Read–Write Genome Evolution as an Active Biological Process. *Biology* 5(2): 27.
- Thoulouze, M.-I. and Alcover, A. 2011. Can viruses form biofilms? *Trends in Microbiology* 19(6): 257–262.
- Trinh, J.T. , Székely, T. , Shao, Q. , Balázs, G. and Zeng, L. 2017. Cell fate decisions emerge as phages cooperate or compete inside their host. *Nature Communications* 8: 14341.
- Villarreal, L.P. 2005. *Viruses And The Evolution Of Life*. Washington, D.C.: Amer Society for Microbiology(ASM) Press.
- Villarreal, L.P. 2007. Virus-host symbiosis mediated by persistence. *Symbiosis* 44: 1–9.
- Villarreal, L.P. and Witzany, G. 2010. Viruses are essential agents within the roots and stem of the tree of life. *Journal of Theoretical Biology* 262(4): 698–710.
- Villarreal, L.P. and Witzany, G. 2013. Rethinking quasispecies theory: From fittest type to cooperative consortia. *World Journal of Biological Chemistry* 4(4): 79.
- Villarreal, L.P. and Witzany, G. 2021. Social Networking of Quasi-Species Consortia drive Virovolution via Persistence. *AIMS Microbiology* 7(2): 138–162.
- Virgin, H.W. 2014. The Virome in Mammalian Physiology and Disease. *Cell* 157(1): 142–150.

- Wang, Q. , Guan, Z. , Pei, K. , Wang, J. , Liu, Z. , Yin, P. , ... Zou, T. 2018. Structural basis of the arbitrium peptide–AimR communication system in the phage lysis–lysogeny decision. *Nature Microbiology* 3(11): 1266–1273.
- Wilke, C.O. and Novella, I.S. 2003. Phenotypic mixing and hiding may contribute to memory in viral quasispecies. *BMC Microbiology* 3: 11.
- Witzany, G. 2020. What Does Communication of Phages Mean? pp. 1–22. In: *Biocommunication of Phages*. Springer Cham.
- Zhang, Y.-Z. , Chen, Y.-M. , Wang, W. , Qin, X.-C. and Holmes, E.C. 2019. Expanding the RNA Virosphere by Unbiased Metagenomics. *Annual Review of Virology* 6(1): 119–139.

## Holobionts: A Consensual 'We'

- Altmäe, S. , Franasiak, J.M. and Mändar, R. 2019. The seminal microbiome in health and disease. *Nature Reviews Urology* 16(12): 703–721.
- Aykut, B. , Pushalkar, S. , Chen, R. , Li, Q. , Abengozar, R. , Kim, J.I. , ... Miller, G. 2019. The fungal mycobiome promotes pancreatic oncogenesis via activation of MBL. *Nature* 574(7777): 264–267.
- Bäckhed, F. , Ley, R.E. , Sonnenburg, J.L. , Peterson, D.A. and Gordon, J.I. 2005. Host-Bacterial Mutualism in the Human Intestine. *Science* 307(5717): 1915–1920.
- Bohm, D.J. and Hiley, B.J. 1975. On the intuitive understanding of nonlocality as implied by quantum theory. *Foundations of Physics* 5: 93–109.
- Burcham, Z.M. , Pechal, J.L. , Schmidt, C.J. , Bose, J.L. , Rosch, J.W. , Benbow, M.E. and Jordan, H.R. 2019. Bacterial Community Succession, Transmigration, and Differential Gene Transcription in a Controlled Vertebrate Decomposition Model. *Frontiers in Microbiology* 10: 745.
- Carrizales-Sánchez, A.K. , García-Cayuela, T. , Hernández-Brenes, C. and Senés-Guerrero, C. 2021. Gut microbiota associations with metabolic syndrome and relevance of its study in pediatric subjects. *Gut Microbes* 13(1): e1960135.
- Chiu, L. and Gilbert, S.F. 2015. The Birth of the Holobiont: Multi-species Birthing Through Mutual Scaffolding and Niche Construction. *Biosemiotics* 8(2): 191–210.
- Cho, I. and Blaser, M.J. 2012. The human microbiome: at the interface of health and disease. *Nature Reviews Genetics* 13(4): 260–270.
- Cryan, J.F. and Dinan, T.G. 2012. Mind-altering microorganisms: the impact of the gut microbiota on brain and behaviour. *Nature Reviews Neuroscience* 13(10): 701–712.
- Foo, J.L. , Ling, H. , Lee, Y.S. and Chang, M.W. 2017. Microbiome engineering: Current applications and its future. *Biotechnology Journal* 12(3): 1600099.
- Geller, L.T. , Barzily-Rokni, M. , Danino, T. , Jonas, O.H. , Shental, N. , Nejman, D. , ... Straussman, R. 2017. Potential role of intratumor bacteria in mediating tumor resistance to the chemotherapeutic drug gemcitabine. *Science* 357(6356): 1156–1160.
- Gilbert, J.A. , Blaser, M.J. , Caporaso, J.G. , Jansson, J.K. , Lynch, S.V. and Knight, R. 2018. Current understanding of the human microbiome. *Nature Medicine* 24(4): 392–400.
- Gilbert, S.F. 2014. Symbiosis as the way of eukaryotic life: The dependent co-origination of the body. *Journal of Biosciences* 39(2): 201–209.
- Gilbert, S.F. , McDonald, E. , Boyle, N. , Buttino, N. , Gyi, L. , Mai, M. , ... Robinson, J. 2010. Symbiosis as a source of selectable epigenetic variation: taking the heat for the big guy. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365(1540): 671–678.
- Gordon, J. , Knowlton, N. , Relman, D.A. , Rohwer, F. and Youle, M. 2013. Superorganisms and holobionts. *Microbe* 8: 152–153.
- Heijtz, R.D. , Wang, S. , Anuar, F. , Qian, Y. , Björkholm, B. , Samuelsson, A. , ... Pettersson, S. 2011. Normal gut microbiota modulates brain development and behavior. *Proceedings of the National Academy of Sciences* 108(7): 3047–3052.
- Hendry, A.P. 2016. Key Questions on the Role of Phenotypic Plasticity in Eco-Evolutionary Dynamics. *Journal of Heredity* 107(1): 25–41.
- Hernandez, C.J. , Guss, J.D. , Luna, M. and Goldring, S.R. 2016. Links Between the Microbiome and Bone. *Journal of Bone and Mineral Research* 31(9): 1638–1646.

- Ho, M.-W. 2008. *The Rainbow and the Worm: The Physics of Organisms* (3rd ed.). Singapore: World Scientific Publishing Company.
- Hooper, L.V. , Littman, D.R. and Macpherson, A.J. 2012. Interactions Between the Microbiota and the Immune System. *Science* 336(6086): 1268–1273.
- Huitzil, S. , Sandoval-Motta, S. , Frank, A. and Aldana, M. 2018. Modeling the Role of the Microbiome in Evolution. *Frontiers in Physiology* 9(1836).
- Jochum, L. and Stecher, B. 2020. Label or Concept—What Is a Pathobiont? *Trends in Microbiology* 28(10): 789–792.
- John, G.K. and Mullin, G.E. 2016. The Gut Microbiome and Obesity. *Current Oncology Reports* 18(7): 45.
- Kelly, J.R. , Minuto, C. , Cryan, J.F. , Clarke, G. and Dinan, T.G. 2017. Cross Talk: The Microbiota and Neurodevelopmental Disorders. *Frontiers in Neuroscience* 11(490).
- Lee, C.J. , Sears, C.L. and Maruthur, N. 2020. Gut microbiome and its role in obesity and insulin resistance. *Annals of the New York Academy of Sciences* 1461(1): 37–52.
- Lefebvre, F.A. and Lécuyer, E. 2017. Small Luggage for a Long Journey: Transfer of Vesicle-Enclosed Small RNA in Interspecies Communication. *Frontiers in Microbiology* 8(377).
- Leitão, A.L. , Costa, M.C. , Gabriel, A.F. and Enguita, F.J. 2020. Interspecies Communication in Holobionts by Non-Coding RNA Exchange. *International Journal of Molecular Sciences* 21(7): 2333.
- Lian, S. , Liu, J. , Wu, Y. , Xia, P. and Zhu, G. 2022. Bacterial and Viral Co-Infection in the Intestine: Competition Scenario and Their Effect on Host Immunity. *International Journal of Molecular Sciences* 23(4): 2311.
- Liang, G. and Bushman, F.D. 2021. The human virome: assembly, composition and host interactions. *Nature Reviews Microbiology* 19(8): 514–527.
- Łukasik, P. , van Asch, M. , Guo, H. , Ferrari, J. and Charles, J. , Godfray, H. 2013. Unrelated facultative endosymbionts protect aphids against a fungal pathogen. *Ecology Letters* 16(2): 214–218.
- Lynch, J.B. and Hsiao, E.Y. 2019. Microbiomes as sources of emergent host phenotypes. *Science* 365(6460): 1405–1409.
- Mayneris-Perxachs, J. , Castells-Nobau, A. , Arnoriaga-Rodríguez, M. , Garre-Olmo, J. , Puig, J. , Ramos, R. , ... Fernández-Real, J.-M. 2022. Caudovirales bacteriophages are associated with improved executive function and memory in flies, mice, and humans. *Cell Host & Microbe* 30(3): 340–356.e8.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016a. Cognition, Information Fields and Hologenic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2016b. The Eukaryotic Microbiome: Origins and Implications for Fetal and Neonatal Life. *Frontiers in Pediatrics* 4(96).
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1–26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.
- Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of “self”. *Progress in Biophysics and Molecular Biology* 142: 54–74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.
- Mishra, A. , Lai, G.C. , Yao, L.J. , Aung, T.T. , Shental, N. , Rotter-Maskowitz, A. , ... Ginhoux, F. 2021. Microbial exposure during early human development primes fetal immune cells. *Cell* 184(13): 3394–3409.e20.
- Miyoshi, J. and Chang, E.B. 2017. The gut microbiota and inflammatory bowel diseases. *Translational Research* 179: 38–48.
- Morar, N. and Bohannan, B.J.M. 2019. The Conceptual Ecology of the Human Microbiome. *The Quarterly Review of Biology* 94(2): 149–175.

- Moya, A. , Peretó, J. , Gil, R. and Latorre, A. 2008. Learning how to live together: genomic insights into prokaryote–animal symbioses. *Nature Reviews Genetics* 9(3): 218–229.
- Mu, J. , Zhuang, X. , Wang, Q. , Jiang, H. , Deng, Z. , Wang, B. , ... Zhang, H. 2014. Interspecies communication between plant and mouse gut host cells through edible plant derived exosomal-like nanoparticles. *Molecular Nutrition & Food Research* 58(7): 1561–1573.
- Ñahui Palomino, R.A. , Vanpouille, C. , Costantini, P.E. and Margolis, L. 2021. Microbiota–host communications: Bacterial extracellular vesicles as a common language. *PLOS Pathogens* 17(5): e1009508.
- Nguyen, T.T. , Kosciolk, T. , Eyler, L.T. , Knight, R. and Jeste, D.V. 2018. Overview and systematic review of studies of microbiome in schizophrenia and bipolar disorder. *Journal of Psychiatric Research* 99: 50–61.
- Nicholson, D.J. 2014. The machine conception of the organism in development and evolution: A critical analysis. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 48: 162–174.
- Noble, D. 2015. Evolution beyond neo-Darwinism: a new conceptual framework. *Journal of Experimental Biology* 218(8): 1273.
- Noble, R. and Noble, D. 2018. Harnessing stochasticity: How do organisms make choices? *Chaos: An Interdisciplinary Journal of Nonlinear Science* 28(10): 106309.
- O'Hara, A.M. and Shanahan, F. 2006. The gut flora as a forgotten organ. *EMBO Reports* 7(7): 688–693.
- O'Malley, M.A. 2017. From endosymbiosis to holobionts: Evaluating a conceptual legacy. *Journal of Theoretical Biology* 434: 34–41.
- Parker, E.L. , Silverstein, R.B. and Mysorekar, I.U. 2021. Bacteria make T cell memories in utero. *Cell* 184(13): 3356–3357.
- Postler, T.S. and Ghosh, S. 2017. Understanding the Holobiont: How Microbial Metabolites Affect Human Health and Shape the Immune System. *Cell Metabolism* 26(1): 110–130.
- Pulikkan, J. , Mazumder, A. and Grace, T. 2019. Role of the Gut Microbiome in Autism Spectrum Disorders. In: P.C. Guest (ed.). *Reviews on Biomarker Studies in Psychiatric and Neurodegenerative Disorders* (Vol. 1118, pp. 253–269). Cham, Switzerland: Springer.
- Roossinck, M.J. 2015. Move Over, Bacteria! Viruses Make Their Mark as Mutualistic Microbial Symbionts. *Journal of Virology* 89(13): 6532–6535.
- Rosenberg, E. , Sharon, G. and Zilber-Rosenberg, I. 2009. The hologenome theory of evolution contains Lamarckian aspects within a Darwinian framework. *Environmental Microbiology* 11(12): 2959–2962.
- Rosenberg, E. and Zilber-Rosenberg, I. 2011. Symbiosis and development: The hologenome concept. *Birth Defects Research Part C: Embryo Today: Reviews* 93(1): 56–66.
- Round, J.L. and Mazmanian, S.K. 2009. The gut microbiota shapes intestinal immune responses during health and disease. *Nature Reviews Immunology* 9(5): 313–323.
- Ryan, F. 2020. Viral Symbiosis in the Origins and Evolution of Life with a Particular Focus on the Placental Mammals. pp. 3–24. In: *Symbiosis: Cellular, Molecular, Medical and Evolutionary Aspects*. Cham, Switzerland: Springer.
- Saetzler, K. , Sonnenschein, C. and Soto, A.M. 2011. Systems biology beyond networks: Generating order from disorder through self-organization. *Seminars in Cancer Biology* 21(3): 165–174.
- Schneider, R.F. and Meyer, A. 2017. How plasticity, genetic assimilation and cryptic genetic variation may contribute to adaptive radiations. *Molecular Ecology* 26(1): 330–350.
- Sender, R. , Fuchs, S. and Milo, R. 2016. Revised Estimates for the Number of Human and Bacteria Cells in the Body. *PLOS Biology* 14(8): e1002533.
- Stan, R.C. , Bhatt, D.K. and Camargo, M.M. 2020. Cellular Adaptation Relies on Regulatory Proteins Having Episodic Memory. *BioEssays* 42(1): 1900115.
- Stiemsma, L.T. and Michels, K.B. 2018. The Role of the Microbiome in the Developmental Origins of Health and Disease. *Pediatrics* 141(4): e20172437.
- Suki, B. 2012. The Major Transitions of Life from a Network Perspective. *Frontiers in Physiology* 3.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Vogtmann, E. and Goedert, J.J. 2016. Epidemiologic studies of the human microbiome and cancer. *British Journal of Cancer* 114(3): 237–242.

Xia, J. , Guo, Z. , Yang, Z. , Han, H. , Wang, S. , Xu, H. , ... Zhang, Y. 2021. Whitefly hijacks a plant detoxification gene that neutralizes plant toxins. *Cell* 184(7): 1693–1705.e17.

Zakis, D.R. , Paulissen, E. , Kornete, L. , Kaan, A.M. (Marije), Nicu, E.A. and Zaura, E. 2022. The evidence for placental microbiome and its composition in healthy pregnancies: A systematic review. *Journal of Reproductive Immunology* 149: 103455.

## The Role of the Microbiome in the Evolution and Development of Holobionts

Achtman, M. and Wagner, M. 2008. Microbial diversity and the genetic nature of microbial species. *Nature Reviews Microbiology* 6(6): 431–440.

Agler, M.T. , Ruhe, J. , Kroll, S. , Morhenn, C. , Kim, S.-T. , Weigel, D. and Kemen, E.M. 2016. Microbial Hub Taxa Link Host and Abiotic Factors to Plant Microbiome Variation. *PLOS Biology* 14(1): e1002352.

Alberdi, A. , Aizpurua, O. , Bohmann, K. , Zepeda-Mendoza, M.L. and Gilbert, M.T.P. 2016. Do Vertebrate Gut Metagenomes Confer Rapid Ecological Adaptation? *Trends in Ecology & Evolution* 31(9): 689–699.

Amato, K.R.G. , Sanders, J. , Song, S.J. , Nute, M. , Metcalf, J.L. , Thompson, L.R.R. .... Leigh, S. 2018. Evolutionary trends in host physiology outweigh dietary niche in structuring primate gut microbiomes. *The ISME Journal* 13(3): 576–587.

Amato, K.R.G. , Sanders, J. , Song, S.J. , Nute, M. , Metcalf, J.L. , Thompson, L.R.R. .... Leigh, S. 2019. Evolutionary trends in host physiology outweigh dietary niche in structuring primate gut microbiomes. *The ISME Journal* 13(3): 576–587.

Annala, A. and Baverstock, K. 2014. Genes without prominence: a reappraisal of the foundations of biology. *Journal of The Royal Society Interface* 11(94): 20131017.

Augustin, R. , Schröder, K. , Murillo Rincón, A.P. , Fraune, S. , Anton-Erxleben, F. , Herbst, E.-M. , ... Bosch, T.C.G. . 2017. A secreted antibacterial neuropeptide shapes the microbiome of Hydra. *Nature Communications* 8: 698.

Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178: 106–119.

Bastiaanssen, T.F.S. , Cusotto, S. , Claesson, M.J. , Clarke, G. , Dinan, T.G. and Cryan, J.F. 2020. Gutted! Unraveling the Role of the Microbiome in Major Depressive Disorder. *Harvard Review of Psychiatry* 28(1): 26–39.

Bauer, E. , Laczny, C.C. , Magnusdottir, S. , Wilmes, P. and Thiele, I. 2015. Phenotypic differentiation of gastrointestinal microbes is reflected in their encoded metabolic repertoires. *Microbiome* 3: 55.

Bell, J.S. , Spencer, J.I. , Yates, R.L. , Yee, S.A. , Jacobs, B.M. and DeLuca, G.C. 2019. Invited Review: From nose to gut—the role of the microbiome in neurological disease. *Neuropathology and Applied Neurobiology* 45(3): 195–215.

Berendsen, R.L. , Pieterse, C.M.J. and Bakker, P.A.H.M. 2012. The rhizosphere microbiome and plant health. *Trends in Plant Science* 17(8): 478–486.

Bing, X. , Attardo, G.M. , Vigneron, A. , Aksoy, E. , Scolari, F. , Malacrida, A. , ... Aksoy, S. 2017. Unravelling the relationship between the tsetse fly and its obligate symbiont *Wigglesworthia* : transcriptomic and metabolomic landscapes reveal highly integrated physiological networks. *Proceedings of the Royal Society B: Biological Sciences* 284(1857): 20170360.

Blackmer-Raynolds, L.D. and Sampson, T.R. 2022. The gut-brain axis goes viral. *Cell Host & Microbe* 30(3): 283–285.

Boto, L. , Pineda, M. and Pineda, R. 2019. Potential impacts of horizontal gene transfer on human health and physiology and how anthropogenic activity can affect it. *The FEBS Journal* 286(20): 3959–3967.

Bray, D. 2009. *Wetware: A Computer in Every Living Cell*. Yale University Press.

Brooks, A.W. , Kohl, K.D. , Brucker, R.M. , van Opstal, E.J. and Bordenstein, S.R. 2016. Phylosymbiosis: Relationships and Functional Effects of Microbial Communities across Host Evolutionary History. *PLOS Biology* 14(11): e2000225.

- Chiu, L. , Bazin, T. , Truchetet, M.-E. , Schaeveerbeke, T. , Delhaes, L. and Pradeu, T. 2017. Protective Microbiota: From Localized to Long-Reaching Co-Immunity. *Frontiers in Immunology* 8(1678).
- Chiu, L. and Gilbert, S.F. 2015. The Birth of the Holobiont: Multi-species Birthing Through Mutual Scaffolding and Niche Construction. *Biosemiotics* 8(2): 191–210.
- Cryan, J.F. and Dinan, T.G. 2012. Mind-altering microorganisms: the impact of the gut microbiota on brain and behaviour. *Nature Reviews Neuroscience* 13(10): 701–712.
- de Goffau, M.C. , Lager, S. , Sovio, U. , Gaccioli, F. , Cook, E. , Peacock, S.J. , ... Smith, G.C.S. . 2019. Human placenta has no microbiome but can contain potential pathogens. *Nature* 572(7769): 329–334.
- Deichmann, U. 2016. Epigenetics: The origins and evolution of a fashionable topic. *Developmental Biology* 416(1): 249–254.
- Dominguez-Bello, M.G. , Godoy-Vitorino, F. , Knight, R. and Blaser, M.J. 2019. Role of the microbiome in human development. *Gut* 68(6): 1108–1114.
- Douglas, A.E. and Werren, J.H. 2016. Holes in the Hologenome: Why Host-Microbe Symbioses Are Not Holobionts. *MBio* 7(2): e02099–15.
- Enaud, R. , Vandenberght, L.-E. , Coron, N. , Bazin, T. , Prevel, R. , Schaeveerbeke, T. , ... Delhaes, L. 2018. The Mycobioime: A Neglected Component in the Microbiota-Gut-Brain Axis. *Microorganisms* 6(1): 22.
- Flayer, C.H. and Sokol, C.L. 2020. Nerves of Steel: How the Gut Nervous System Promotes a Strong Barrier. *Cell* 180(1): 15–17.
- Ghosh, T. , Almeida, R.G. , Zhao, C. , Gonzale, M.G. , Stott, K. , Adams, I. , ... Franklin, R.J. 2022. A retroviral origin of vertebrate myelin. *BioRxiv*.
- Gilbert, S.F. 2014. A holobiont birth narrative: the epigenetic transmission of the human microbiome. *Frontiers in Genetics*, 5.
- Gilbert, S.F. , McDonald, E. , Boyle, N. , Buttino, N. , Gyi, L. , Mai, M. , ... Robinson, J. 2010. Symbiosis as a source of selectable epigenetic variation: taking the heat for the big guy. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365(1540): 671–678.
- Gordon, J. , Knowlton, N. , Relman, D.A. , Rohwer, F. and Youle, M. 2013. Superorganisms and holobionts. *Microbe* 8(4): 152–153.
- Henry, L.P. , Bruijning, M. , Forsberg, S.K.G. and Ayroles, J.F. 2019. Can the microbiome influence host evolutionary trajectories? *BioRxiv* (700237).
- Henry, L.P. , Bruijning, M. , Forsberg, S.K.G. and Ayroles, J.F. 2021. The microbiome extends host evolutionary potential. *Nature Communications* 12: 5141.
- Hongoh, Y. 2010. Diversity and Genomes of Uncultured Microbial Symbionts in the Termite Gut. *Bioscience, Biotechnology, and Biochemistry* 74(6): 1145–1151.
- Huitzil, S. , Sandoval-Motta, S. , Frank, A. and Aldana, M. 2018. Modeling the Role of the Microbiome in Evolution. *Frontiers in Physiology* 9(1836).
- Hummel, G.L. , Austin, K. and Cunningham-Hollinger, H.C. 2022. Comparing the maternal-fetal microbiome of humans and cattle: a translational assessment of the reproductive, placental, and fetal gut microbiomes. *Biology of Reproduction*, 107(2): 371–381.
- Huseyin, C.E. , O'Toole, P.W. , Cotter, P.D. and Scanlan, P.D. 2017. Forgotten fungi—the gut mycobioime in human health and disease. *FEMS Microbiology Reviews* 41(4): 479–511.
- Jaspers, C. , Fraune, S. , Arnold, A.E. , Miller, D.J. , Bosch, T.C.G. and Voolstra, C.R. 2019. Resolving structure and function of metaorganisms through a holistic framework combining reductionist and integrative approaches. *Zoology* 133: 81–87.
- Jenmalm, M.C. 2017. The mother-offspring dyad: microbial transmission, immune interactions and allergy development. *Journal of Internal Medicine* 282(6): 484–495.
- Jeong, H. , Arif, B. , Caetano-Anollés, G. , Kim, K.M. and Nasir, A. 2019. Horizontal gene transfer in human-associated microorganisms inferred by phylogenetic reconstruction and reconciliation. *Scientific Reports* 9(5953).
- Jiménez, E. , Fernández, L. , Marín, M.L. , Martín, R. , Odriozola, J.M. , Nueno-Palop, C. , ... Rodríguez, J.M. 2005. Isolation of Commensal Bacteria from Umbilical Cord Blood of Healthy Neonates Born by Cesarean Section. *Current Microbiology* 51(4): 270–274.
- Kauffman, S. 1995. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity*. New York NY, United States: Oxford University Press.
- Kong, H.H. and Morris, A. 2017. The emerging importance and challenges of the human mycobioime. *Virulence* 8(3): 310–312.

Koonin, E.V. 2009. Darwinian evolution in the light of genomics. *Nucleic Acids Research* 37(4): 1011–1034.

Krüger, W. , Vielreicher, S. , Kapitan, M. , Jacobsen, I. and Niemiec, M. 2019. Fungal-Bacterial Interactions in Health and Disease. *Pathogens* 8(2): 70.

Kumar, A. , Alam, A. , Rani, M. , Ehtesham, N.Z. and Hasnain, S.E. 2017. Biofilms: Survival and defense strategy for pathogens. *International Journal of Medical Microbiology* 307(8): 481–489.

Laforest-Lapointe, I. , Paquette, A. , Messier, C. and Kembel, S.W. 2017. Leaf bacterial diversity mediates plant diversity and ecosystem function relationships. *Nature* 546(7656): 145–147.

Lee, M.D. , Kling, J.D. , Araya, R. and Ceh, J. 2018. Jellyfish Life Stages Shape Associated Microbial Communities, While a Core Microbiome Is Maintained Across All. *Frontiers in Microbiology* 9: 1534.

Lickwar, C.R. , Davison, J.M. , Kelly, C. , Mercado, G.P. , Wen, J. , Davis, B.R. , ... Rawls, J.F. 2022. Transcriptional Integration of Distinct Microbial and Nutritional Signals by the Small Intestinal Epithelium. *Cellular and Molecular Gastroenterology and Hepatology* 14(2): 465–493.

Madhusoodanan, J. 2019. Do hosts and their microbes evolve as a unit? *Proceedings of the National Academy of Sciences* 116(29): 14391–14394.

Martínez-Hidalgo, P. and Hirsch, A.M. 2017. The Nodule Microbiome: N<sub>2</sub>-Fixing Rhizobia Do Not Live Alone. *Phytobiomes Journal* 1(2): 70–82.

Mayneris-Perxachs, J. , Castells-Nobau, A. , Arnoriaga-Rodríguez, M. , Garre-Olmo, J. , Puig, J. , Ramos, R. , ... Fernández-Real, J.-M. 2022. Caudovirales bacteriophages are associated with improved executive function and memory in flies, mice, and humans. *Cell Host & Microbe* 30(3): 340–356.e8.

McFall-Ngai, M. , Hadfield, M.G. , Bosch, T.C.G. , Carey, H.V. , Domazet-Lošo, T. , Douglas, A.E. , ... Wernegreen, J.J. 2013. Animals in a bacterial world, a new imperative for the life sciences. *Proceedings of the National Academy of Sciences* 110(9): 3229–3236.

Mendes-Soares, H. and Chia, N. 2017. Community metabolic modeling approaches to understanding the gut microbiome: Bridging biochemistry and ecology. *Free Radical Biology and Medicine* 105: 102–109.

Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.

Miller, W.B. 2016a. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.

Miller, W.B. 2016b. The Eukaryotic Microbiome: Origins and Implications for Fetal and Neonatal Life. *Frontiers in Pediatrics* 4(96).

Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1–26.

Miller, W.B. , Baluška, F. and Torday, J.S. 2020. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.

Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian CognitionBased Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.

Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of “self”. *Progress in Biophysics and Molecular Biology* 142: 54–74.

Mirahmadizadeh, A. , Yaghoobi, R. and Soleimani, S. 2019. Viral ecosystem: An epidemiological hypothesis. *Reviews in Medical Virology* 29(4): e2053.

Mishra, S. , Hättenschwiler, S. and Yang, X. 2020. The plant microbiome: A missing link for the understanding of community dynamics and multifunctionality in forest ecosystems. *Applied Soil Ecology* 145: 103345.

Mittelman, K. and Burstein, D. 2019. Tiny Hidden Genes within Our Microbiome. *Cell* 178(5): 1034–1035.

Moeller, A.H. , Caro-Quintero, A. , Mjungu, D. , Georgiev, A.V. , Lonsdorf, E.V. , Muller, M.N. , ... Ochman, H. 2016. Cospeciation of gut microbiota with hominids. *Science* 353(6297): 380–382.

Moeller, A.H. , Li, Y. , Mpoudi Ngole, E. , Ahuka-Mundeke, S. , Lonsdorf, E.V. , Pusey, A.E. , ... Ochman, H. 2014. Rapid changes in the gut microbiome during human evolution. *Proceedings of the National Academy of Sciences* 111(46): 16431–16435.

Moeller, A.H. , Suzuki, T.A. , Phifer-Rixey, M. and Nachman, M.W. 2018. Transmission modes of the mammalian gut microbiota. *Science* 362(6413): 453–457.

- Montgomery, M.K. and McFall-Ngai, M. 1994. Bacterial symbionts induce host organ morphogenesis during early postembryonic development of the squid *Euprymna scolopes*. *Development* 120(7): 1719–1729.
- Morris, J.J. 2018. What is the hologenome concept of evolution? *F1000Research* 7: 1664.
- Müller, D.B. , Vogel, C. , Bai, Y. and Vorholt, J.A. 2016. The Plant Microbiota: Systems-Level Insights and Perspectives. *Annual Review of Genetics* 50: 211–234.
- Nkamga, V.D. , Henrissat, B. and Drancourt, M. 2017. Archaea: Essential inhabitants of the human digestive microbiota. *Human Microbiome Journal* 3: 1–8.
- Peng, J. , Xiao, X. , Hu, M. and Zhang, X. 2018. Interaction between gut microbiome and cardiovascular disease. *Life Sciences* 214: 153–157.
- Perofsky, A.C. , Ance Meyers, L. , Abondano, L.A. , Di Fiore, A. and Lewis, R.J. 2021. Social groups constrain the spatiotemporal dynamics of wild sifaka gut microbiomes. *Molecular Ecology* 30(24): 6759–6775.
- Pigliucci, M. 2017. Darwinism After the Modern Synthesis. pp. 89–103. In: R.G. Delisle (ed.). *The Darwinian Tradition in Context*. Cham: Springer.
- Pita, L. , Rix, L. , Slaby, B.M. , Franke, A. and Hentschel, U. 2018. The sponge holobiont in a changing ocean: from microbes to ecosystems. *Microbiome* 6(1): 46.
- Quince, C. , Walker, A.W. , Simpson, J.T. , Loman, N.J. and Segata, N. 2017. Shotgun metagenomics, from sampling to analysis. *Nature Biotechnology* 35(9): 833–844.
- Richard, M.L. and Sokol, H. 2019. The gut mycobiota: insights into analysis, environmental interactions and role in gastrointestinal diseases. *Nature Reviews Gastroenterology & Hepatology* 16(6): 331–345.
- Roossinck, M.J. 2015. Move Over, Bacteria! Viruses Make Their Mark as Mutualistic Microbial Symbionts. *Journal of Virology* 89(13): 6532–6535.
- Roossinck, M.J. and Bazán, E.R. 2017. Symbiosis: Viruses as Intimate Partners. *Annual Review of Virology* 4: 123–139.
- Rosenberg, E. and Zilber-Rosenberg, I. 2016. Microbes Drive Evolution of Animals and Plants: the Hologenome Concept. *MBio* 7(2): e01395.
- Ryan, F. 2009. *Viroolution*. New York, NY, USA: HarperCollins Publishers.
- Ryan, F. 2010. You are half virus. *New Scientist* 205(2745): 32–35.
- Sandoval-Motta, S. , Aldana, M. and Frank, A. 2017. Evolving Ecosystems: Inheritance and Selection in the Light of the Microbiome. *Archives of Medical Research* 48(8): 780–789.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Sharma, A. 2015a. Systems genomics analysis centered on epigenetic inheritance supports development of a unified theory of biology. *Journal of Experimental Biology*.
- Sharma, A. 2015b. Transgenerational epigenetic inheritance: resolving uncertainty and evolving biology. *Biomolecular Concepts* 6(2): 87–103.
- Sharma, U. , Sun, F. , Conine, C.C. , Reichholz, B. , Kukreja, S. , Herzog, V.A. , ... Rando, O.J. 2018. Small RNAs Are Trafficked from the Epididymis to Developing Mammalian Sperm. *Developmental Cell*, 46(4): 481–494.e6.
- Shropshire, J.D. and Bordenstein, S.R. 2016. Speciation by Symbiosis: the Microbiome and Behavior. *MBio* 7(2): e01785.
- Soucy, S.M. , Huang, J. and Gogarten, J.P. 2015. Horizontal gene transfer: building the web of life. *Nature Reviews Genetics* 16(8): 472–482.
- Spadafora, C. 2018. The “evolutionary field” hypothesis. Non-Mendelian transgenerational inheritance mediates diversification and evolution. *Progress in Biophysics and Molecular Biology* 134: 27–37.
- Stinson, L.F. , Payne, M.S. and Keelan, J.A. 2017. Planting the seed: Origins, composition, and postnatal health significance of the fetal gastrointestinal microbiota. *Critical Reviews in Microbiology* 43(3): 352–369.
- Surani, M.A. 2016. Breaking the germ line–soma barrier. *Nature Reviews Molecular Cell Biology* 17(3): 136.
- Suzuki, T.A. , Fitzstevens, J.L. , Schmidt, V.T. , Enav, H. , Huus, K.E. , Mbong Ngwese, M. , Griehammer, A. , Pfeleiderer, A. , Adegbite, B.R. , Zinsou, J.F. and Esen, M. 2022. Codiversification of gut microbiota with humans. *Science* 377(6612): 1328–1332.
- Torday, J. and Miller, W. 2016a. Phenotype as Agent for Epigenetic Inheritance. *Biology* 5(3): 30.

- Torday, J. and Miller, W. 2016b The Unicellular State as a Point Source in a Quantum Biological System. *Biology* 5(2): 25.
- Torday, J. and Miller, W. 2020. Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology Cham, Switzerland: Springer.
- Tripathy, A. and Pradhan, R.K. 2018. Symbiotic Interactions, Law of Purposive Association and the+/+ Nature of all Co-evolution. *Indian Journal of Science and Technology* 11: 43.
- Turner, T.R. , James, E.K. and Poole, P.S. 2013. The plant microbiome. *Genome Biology* 14(6): 209.
- Vacher, C. , Hampe, A. , Porté, A.J. , Sauer, U. , Compant, S. and Morris, C.E. 2016. The Phyllosphere: Microbial Jungle at the Plant–Climate Interface. *Annual Review of Ecology, Evolution, and Systematics* 47: 1–24.
- van der Heijden, M.G.A. and Hartmann, M. 2016. Networking in the Plant Microbiome. *PLOS Biology* 14(2): e1002378.
- Vernier, C.L. , Chin, I.M. , Adu-Oppong, B. , Krupp, J.J. , Levine, J. , Dantas, G. and Ben-Shahar, Y. 2020. The gut microbiome defines social group membership in honey bee colonies. *Science Advances* 6(42).
- Villarreal, L.P. and Witzany, G. 2010. Viruses are essential agents within the roots and stem of the tree of life. *Journal of Theoretical Biology* 262(4): 698–710.
- Villarreal, L.P. and Witzany, G. 2018. Editorial: Genome Invading RNA Networks. *Frontiers in Microbiology* 9(581).
- Villarreal, L.P. and Witzany, G. 2019. That is life: communicating RNA networks from viruses and cells in continuous interaction. *Annals of the New York Academy of Sciences* 1447(1): 5–20.
- Williams, K.B. , Bischof, J. , Lee, F.J. , Miller, K.A. , LaPalme, J.V. , Wolfe, B.E. and Levin, M. 2020. Regulation of axial and head patterning during planarian regeneration by a commensal bacterium. *Mechanisms of Development* 163: 103614.
- Wimberley, E.T. 2009. *Nested Ecology: The Place of Humans in the Ecological Hierarchy*. Baltimore: Johns Hopkins University Press.
- Yao, L. , Seaton, S.C. , Ndousse-Fetter, S. , Adhikari, A.A. , DiBenedetto, N. , Mina, A.I. , ... Devlin, A.S. 2018. A selective gut bacterial bile salt hydrolase alters host metabolism. *ELife* 7: e37182.
- Zakis, D.R. , Paulissen, E. , Kornete, L. , Kaan, A.M.(Marije) , Nicu, E.A. and Zaura, E. 2022. The evidence for placental microbiome and its composition in healthy pregnancies: A systematic review. *Journal of Reproductive Immunology* 149: 103455.
- Zárate, S. , Taboada, B. , Yocupicio-Monroy, M. and Arias, C.F. 2017. Human Virome. *Archives of Medical Research* 48(8): 701–716.
- Zhang, Y. , Su, X. , Harris, A. , Caraballo-Ortiz, M.A. , Ren, Z. and Zhong, Y. 2018. Genetic Structure of the Bacterial Endosymbiont *Buchnera aphidicola* from Its Host Aphid *Schlechtendalia chinensis* and Evolutionary Implications. *Current Microbiology* 75(3): 309–315.
- Zilber-Rosenberg, I. and Rosenberg, E. 2008. Role of microorganisms in the evolution of animals and plants: the hologenome theory of evolution. *FEMS Microbiology Reviews* 32(5): 723–735.
- Zmora, N. , Suez, J. and Elinav, E. 2019. You are what you eat: diet, health and the gut microbiota. *Nature Reviews Gastroenterology & Hepatology* 16(1): 35–56

## Four Domains and the Primacy of the Unicellular State

- Agnati, L.F. , Baluška, F. , Barlow, P.W. and Guidolin, D. 2009. Mosaic, self-similarity logic and biological attraction principles. *Communicative & Integrative Biology* 2(6): 552–563.
- Bailey, D.H. , Borwein, J.M. , Lopez de Prado, M. and Zhu, Q.J. 2015. The Probability of Back-Test Over-Fitting. *Journal of Computational Finance*, Forthcoming.
- Baluška, F. and Levin, M. 2016. On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology*, 7.
- Baluška, F. and Mancuso, S. 2009. Deep evolutionary origins of neurobiology: Turning the essence of “neural” upside-down. *Communicative & Integrative Biology* 2(1): 60–65.

- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Bechtel, W. 2014. *Cognitive Biology: Surprising Model Organisms for Cognitive Science*. Proceedings of the Annual Meeting of the Cognitive Science Society, 36.
- Betts, H.C. , Puttick, M.N. , Clark, J.W. , Williams, T.A. , Donoghue, P.C.J. and Pisani, D. 2018. Integrated genomic and fossil evidence illuminates life's early evolution and eukaryote origin. *Nature Ecology & Evolution* 2(10): 1556–1562.
- Cai, X. , Wang, X. , Patel, S. and Clapham, D.E. 2015. Insights into the early evolution of animal calcium signaling machinery: A unicellular point of view. *Cell Calcium* 57(3): 166–173.
- Chang, H.H. , Hemberg, M. , Barahona, M. , Ingber, D.E. and Huang, S. 2008. Transcriptome-wide noise controls lineage choice in mammalian progenitor cells. *Nature* 453(7194): 544–547.
- Colson, P. , De Lamballerie, X. , Fournous, G. and Raoult, D. (2012). Reclassification of giant viruses composing a fourth domain of life in the new order Megavirales. *Intervirology* 55(5): 321–332.
- De Loof, A. 2015. Organic and Cultural Evolution can be Seamlessly Integrated Using the Principles of Communication and Problem-Solving: The Foundations for an Extended Evolutionary Synthesis (EES) as Outlined in the Mega-Evolution Concept. *Life: The Excitement of Biology* 2(4): 247–269.
- Deacon, T.W. 2011. *Incomplete Nature: How Mind Emerged from Matter*. New York City, Ny, USA: W. W. Norton & Company.
- Eckersley-Maslin, M.A. , Alda-Catalinas, C. and Reik, W. 2018. Dynamics of the epigenetic landscape during the maternal-to-zygotic transition. *Nature Reviews Molecular Cell Biology* 19(7): 436–450.
- Ford, B.J. 2004. Are Cells Ingenious? *Microscope* 52(3/4): 135–144.
- Ford, B.J. 2009. On Intelligence in Cells: The Case for Whole Cell Biology. *Interdisciplinary Science Reviews*, 34(4), 350–365.
- Ford, B.J. 2017. Cellular intelligence: microphenomenology and the realities of being. *Progress in Biophysics and Molecular Biology* 131: 273–287.
- Forterre, P. and Prangishvili, D. 2009. The origin of viruses. *Research in Microbiology* 160(7): 466–472.
- Friston, K. , Kilner, J. and Harrison, L. 2006. A free energy principle for the brain. *Trends in Cognitive Sciences* 13(7): 293–301.
- Holmes, E.C. 2011. What Does Virus Evolution Tell Us about Virus Origins? *Journal of Virology* 85(11): 5247–5251.
- Hug, L.A. , Baker, B.J. , Anantharaman, K. , Brown, C.T. , Probst, A.J. , Castelle, C.J. , Banfield, J.F. 2016. A new view of the tree of life. *Nature Microbiology* 1(5): 16048.
- Igamberdiev, A.U. and Shklovskiy-Kordi, N.E. 2017. The quantum basis of spatiotemporality in perception and consciousness. *Progress in Biophysics and Molecular Biology* 130: 15–25.
- Jablonski, D. 2004. Extinction: past and present. *Nature* 427(6975): 589.
- Keijzer, F.A. 2017. Evolutionary convergence and biologically embodied cognition. *Interface Focus* 7(3): 20160123.
- Koonin, E.V. and Dolja, V.V. 2014. Virus World as an Evolutionary Network of Viruses and Capsidless Selfish Elements. *Microbiology and Molecular Biology Reviews* 78(2): 278–303.
- Koseska, A. and Bastiaens, P.I. 2017. Cell signaling as a cognitive process. *The EMBO Journal* 36(5): 568–582.
- Lopez de Prado M. 2013. The Probability of Back-Test Over-Fitting. *SSRN Electronic Journal*.
- Loron, C.C. , François, C. , Rainbird, R.H. , Turner, E.C. , Borensztajn, S. and Javaux, E.J. 2019. Early fungi from the Proterozoic era in Arctic Canada. *Nature* 570(7760): 232–235.
- Lowenstein, R. 2000. *When Genius Failed: The Rise and Fall of Long-Term Capital Management*. New York, Ny, United States: Random House.
- Lyon, P. 2015. The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology* 6(264).
- Margulis, L. and Sagan, D. 1997. *Microcosmos: Four billion years of microbial evolution*. Berkley and Los Angeles, CA: Univ of California Press.
- Mattioli, F. , Bhattacharyya, S. , Dyer, P.N. , White, A.E. , Sandman, K. , Burkhart, B.W. , ... Luger, K. 2017. Structure of histone-based chromatin in Archaea. *Science* 357(6351): 609–612.
- McFall-Ngai, M. , Hadfield, M.G. , Bosch, T.C.G. , Carey, H.V. , Domazet-Lošo, T. , Douglas, A.E. , ... Wernegreen, J.J. 2013. Animals in a bacterial world, a new imperative for the life

sciences. *Proceedings of the National Academy of Sciences* 110(9): 3229–3236.

Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.

Miller, W.B. 2016. *Cognition, Information Fields and Hologenic Entanglement: Evolution in Light and Shadow*. *Biology* 5(2): 21.

Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1–26.

Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular genomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.

Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.

Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of “self”. *Progress in Biophysics and Molecular Biology* 142: 54–74.

Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.

Nahum, J.R. , Godfrey-Smith, P. , Harding, B.N. , Marcus, J.H. , Carlson-Stevermer, J. and Kerr, B. 2015. A tortoise–hare pattern seen in adapting structured and unstructured populations suggests a rugged fitness landscape in bacteria. *Proceedings of the National Academy of Sciences* 112(24): 7530–7535.

Noffke, N. , Christian, D. , Wacey, D. and Hazen, R.M. 2013. Microbially Induced Sedimentary Structures Recording an Ancient Ecosystem in the ca. 3.48 Billion-Year-Old Dresser Formation, Pilbara, Western Australia. *Astrobiology* 13(12): 1103–1124.

Papineau, D. , She, Z. , Dodd, M. S. , Iacoviello, F. , Slack, J.F. , Hauri, E. , ... Little, C.T.S. 2022. Metabolically diverse primordial microbial communities in Earth's oldest seafloor-hydrothermal jasper. *Science Advances* 8(15).

Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York, NY, USA: Oxford University Press.

Richter, D.J. and King, N. 2013. The Genomic and Cellular Foundations of Animal Origins. *Annual Review of Genetics* 47: 509–537.

Ryan, F. 2009. *Virolution*. New York, Ny, USA: HarperCollins Publishers.

Shapiro, J.A. 2007. Bacteria are small but not stupid: cognition, natural genetic engineering and socio-bacteriology. *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences*, 38(4): 807–819.

Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.

Sousa, C. 2021. Origin of Life. *The American Biology Teacher* 83(2): 76–79.

Spang, A. , Saw, J.H. , Jørgensen, S.L. , Zaremba-Niedzwiedzka, K. , Martijn, J. , Lind, A.E. , ... Ettema, T.J.G. 2015. Complex archaea that bridge the gap between prokaryotes and eukaryotes. *Nature* 521(7551): 173–179.

Torday, J. and Miller, W. 2016a. The Unicellular State as a Point Source in a Quantum Biological System. *Biology* 5(2): 25.

Torday, J.S. and Miller, W.B. 2016b. Biologic relativity: Who is the observer and what is observed? *Progress in Biophysics and Molecular Biology* 121(1): 29–34.

Torday, J. and Miller, W. 2020a. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.

Torday, J.S. and Miller, W.B. 2020b. Evolution as a timeless continuum. In: J. Guex , J.S. Torday and W.B.J. Miller (eds.). *Morphogenesis, Environmental Stress and Reverse Evolution*. Cham, Switzerland: Springer.

Trewavas, A.J. and Baluška, F. 2011. The ubiquity of consciousness. *EMBO Reports* 12(12): 1221–1225.

Vallverdú, J. , Castro, O. , Mayne, R. , Talanov, M. , Levin, M. , Baluška, F. , ... Adamatzky, A. 2018. Slime mould: The fundamental mechanisms of biological cognition. *Biosystems* 165: 57–70.

Villarreal, L.P. and Ryan, F. 2018. Viruses in the Origin of Life and Its Subsequent Diversification. In: *Handbook of Astrobiology*. Boca Raton, Florida, United States: CRC Press.

Yutin, N. and Koonin, E.V. 2012. Archaeal origin of tubulin. *Biology Direct* 7: 10.

## Speciation

- Abbott, R. , Albach, D. , Ansell, S. , Arntzen, J.W. , Baird, S.J.E. , Bierne, N. , ... Zinner, D. . 2013 Hybridization and speciation. *Journal of Evolutionary Biology* 26(2): 229–246.
- Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178(1): 106–119.
- Belyayev, A. 2014. Bursts of transposable elements as an evolutionary driving force. *Journal of Evolutionary Biology* 27(12): 2573–2584.
- Bennetzen, J.L. and Wang, H. 2014. The Contributions of Transposable Elements to the Structure, Function, and Evolution of Plant Genomes. *Annual Review of Plant Biology* 65: 505–530.
- Black, S.G. , Arnaud, F. , Palmarini, M. and Spencer, T.E. 2010. Endogenous Retroviruses in Trophoblast Differentiation and Placental Development. *American Journal of Reproductive Immunology* 64(4): 255–264.
- Bobay, L.-M. and Ochman, H. 2017. Biological Species Are Universal across Life's Domains. *Genome Biology and Evolution* 9(3): 491–501.
- Boeke, J.D. and Stoye, J.P. 1997. Retrotransposons, endogenous retroviruses, and the evolution of retroelements. In: J.m. Coffin, S.H. Hughes and H.E. Varmus (eds.). *Retroviruses*. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press.
- Boto, L. 2010. Horizontal gene transfer in evolution: facts and challenges. *Proceedings of the Royal Society B: Biological Sciences* 277(1683): 819–827.
- Brandt, J. , Schrauth, S. , Veith, A.-M. , Froschauer, A. , Haneke, T. , Schultheis, C. , ... Volff, J.-N. 2005. Transposable elements as a source of genetic innovation: expression and evolution of a family of retrotransposon-derived neogenes in mammals. *Gene* 345(1): 101–111.
- Brookfield, J. 2002. *Genes, Categories and Species, The Evolutionary and Cognitive Causes of the Species Problem*. J. HEY. Oxford University Press. 2001. 217 pages. ISBN 0 19 514477 5. Price£ 34.95.(hardback). *Genetics Research* 79(1): 107–108.
- Brosius, J. 1999. Genomes were forged by massive bombardments with retroelements and retrosequences. *Genetica* 107(1–3): 209–238.
- Charron, G. , Leducq, J.-B. and Landry, C.R. 2014. Chromosomal variation segregates within incipient species and correlates with reproductive isolation. *Molecular Ecology* 23(17): 4362–4372.
- Chou, J.-Y. , Hung, Y.-S. , Lin, K.-H. , Lee, H.-Y. and Leu, J.-Y. 2010. Multiple Molecular Mechanisms Cause Reproductive Isolation between Three Yeast Species. *PLoS Biology* 8(7): e1000432.
- Coyne, J.A. and Orr, H.A. 2004. *Speciation* (Vol. 37). Sunderland, MA: Sinauer Associates.
- Dobzhansky, T. 1935. A Critique of the Species Concept in Biology. *Philosophy of Science* 2(3): 344–355.
- Eyres, I. , Boschetti, C. , Crisp, A. , Smith, T.P. , Fontaneto, D. , Tunnacliffe, A. and Barraclough, T.G. 2015. Horizontal gene transfer in bdelloid rotifers is ancient, ongoing and more frequent in species from desiccating habitats. *BMC Biology* 13: 90.
- Feschotte, C. and Gilbert, C. 2012. Endogenous viruses: insights into viral evolution and impact on host biology. *Nature Reviews Genetics* 13(4): 283–296.
- Fitzpatrick, B.M. , Fordyce, J.A. and Gavrillets, S. 2008. What, if anything, is sympatric speciation? *Journal of Evolutionary Biology* 21(6): 1452–1459.
- Forterre, P. 2006. The origin of viruses and their possible roles in major evolutionary transitions. *Virus Research* 117(1): 5–16.
- Fraser, C. , Alm, E.J. , Polz, M.F. , Spratt, B.G. and Hanage, W.P. 2009. The Bacterial Species Challenge: Making Sense of Genetic and Ecological Diversity. *Science* 323(5915): 741–746.
- Gavrillets, S. 2003. Perspective: Models of Speciation: What Have We Learned In 40 Years? *Evolution* 57(10): 2197–2215.
- Geoghegan, J.L. , Duchêne, S. and Holmes, E.C. 2017. Comparative analysis estimates the relative frequencies of co-divergence and cross-species transmission within viral families. *PLOS Pathogens* 13(2): e1006215.
- Ghosh, T. , Almeida, R.G. , Zhao, C. , Gonzale, M.G. , Stott, K. , Adams, I. , ... Franklin, R.J. 2022. A retroviral origin of vertebrate myelin. *BioRxiv*.
- Gill, E.E. and Brinkman, F.S.L. 2011. The proportional lack of archaeal pathogens: Do viruses/phages hold the key? *BioEssays* 33(4): 248–254.

- Gladyshev, E.A. , Meselson, M. and Arhipova, I.R. 2008. Massive Horizontal Gene Transfer in Bdelloid Rotifers. *Science* 320(5880): 1210–1213.
- Goldenfeld, N. and Woese, C. 2007. Biology's next revolution. *Nature* 445(7126): 369.
- Grasis, J.A. 2017. The Intra-Dependence of Viruses and the Holobiont. *Frontiers in Immunology* 8(1501).
- Greenwood, A.D. , Ishida, Y. , O'Brien, S.P. , Roca, A.L. and Eiden, M.V. 2018. Transmission, Evolution, and Endogenization: Lessons Learned from Recent Retroviral Invasions. *Microbiology and Molecular Biology Reviews* 82(1): e00044–17.
- Haider, N. 2018. A Brief Review on Species Concepts with Emphasis on Plants. *LS: International Journal of Life Sciences* 7(3): 115–125.
- Hedges, S.B. , Marin, J. , Suleski, M. , Paymer, M. and Kumar, S. 2015. Tree of Life Reveals Clock-Like Speciation and Diversification. *Molecular Biology and Evolution* 32(4): 835–845.
- Hodgins-Davis, A. , Rice, D.P. and Townsend, J.P. 2015. Gene Expression Evolves under a House-of-Cards Model of Stabilizing Selection. *Molecular Biology and Evolution* 32(8): 2130–2140.
- Horie, M. , Honda, T. , Suzuki, Y. , Kobayashi, Y. , Daito, T. , Oshida, T. , ... Tomonaga, K. . 2010. Endogenous non-retroviral RNA virus elements in mammalian genomes. *Nature* 463(7277): 84–87.
- Hua-Van, A. , Le Rouzic, A. , Boutin, T.S. , Filée, J. and Capy, P. 2011. The struggle for life of the genome's selfish architects. *Biology Direct* 6: 19.
- Huang, J.-P. 2018. What Have Been and What Can Be Delimited as Species Using Molecular Data Under the Multi-Species Coalescent Model? A Case Study Using Hercules beetles (Dynastes; Dynastidae). *Insect Systematics and Diversity* 2(2): 3.
- Kinney, M.E. and Pye, G.W. 2016. Koala Retrovirus: A Review. *Journal of Zoo and Wildlife Medicine* 47(2): 387–396.
- Lee, G. , Sherer, N.A. , Kim, N.H. , Rajic, E. , Kaur, D. , Urriola, N. , ... Kuhlman, T.E. 2018. Testing the retroelement invasion hypothesis for the emergence of the ancestral eukaryotic cell. *Proceedings of the National Academy of Sciences* 115(49): 12465–12470.
- Malik, S.S. , Azem-e-Zahra, S. , Kim, K.M. , Caetano-Anollés, G. and Nasir, A. 2017. Do Viruses Exchange Genes across Superkingdoms of Life? *Frontiers in Microbiology* 8.
- Martinez, J. , Klasson, L. , Welch, J.J. and Jiggins, F.M. 2021. Life and Death of Selfish Genes: Comparative Genomics Reveals the Dynamic Evolution of Cytoplasmic Incompatibility. *Molecular Biology and Evolution* 38(1): 2–15.
- Merhej, V. and Raoult, D. 2012. Rhizome of life, catastrophes, sequence exchanges, gene creations, and giant viruses: how microbial genomics challenges Darwin. *Frontiers in Cellular and Infection Microbiology* 2(113).
- Michalak, P. 2009. Epigenetic, transposon and small RNA determinants of hybrid dysfunctions. *Heredity* 102(1): 45–50.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1–26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20–33.
- Miller, W.B. & Torday, J. S. (2018). The Origins of Biological Deception: Ambiguous Information and Human Behavior. *Minding Nature*, 11(3).
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54–74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.
- Monier, A. , Pagarete, A. , de Vargas, C. , Allen, M.J. , Read, B. , Claverie, J.-M. and Ogata, H. 2009. Horizontal gene transfer of an entire metabolic pathway between a eukaryotic alga and its DNA virus. *Genome Research* 19(8): 1441–1449.
- Monroe, J.G. , Srikant, T. , Carbonell-Bejerano, P. , Becker, C. , Lensink, M. , Exposito-Alonso, M. , ... Weigel, D. . 2022. Mutation bias reflects natural selection in *Arabidopsis thaliana*. *Nature*

602(7895): 101–105.

- Oliver, K.R. and Greene, W.K. 2012. Transposable elements and viruses as factors in adaptation and evolution: an expansion and strengthening of the TE-Thrust hypothesis. *Ecology and Evolution* 2(11): 2912–2933.
- Rebollo, R. , Horard, B. , Hubert, B. and Vieira, C. 2010. Jumping genes and epigenetics: Towards new species. *Gene* 454(1–2): 1–7.
- Richardson, K.M. , Griffin, P.C. , Lee, S.F. , Ross, P.A. , Endersby-Harshman, N.M. , Schiffer, M. and Hoffmann, A.A. 2019. A *Wolbachia* infection from *Drosophila* that causes cytoplasmic incompatibility despite low prevalence and densities in males. *Heredity* 122(4): 428–440.
- Rogers, J. , Raveendran, M. , Harris, R.A. , Mailund, T. , Leppälä, K. , Athanasiadis, G. , ... Worley, K.C. 2019. The comparative genomics and complex population history of *Papio* baboons. *Science Advances* 5(1): eaau6947.
- Rosselló-Móra, R. and Amann, R. 2015. Past and future species definitions for Bacteria and Archaea. *Systematic and Applied Microbiology* 38(4): 209–216.
- Ryan, F. 2009. *Viroolution*. New York, Ny, USA: HarperCollins Publishers.
- Ryan, F. 2010. You are half virus. *New Scientist* 205(2745): 32–35.
- Sandoval-Motta, S. , Aldana, M. and Frank, A. 2017. Evolving Ecosystems: Inheritance and Selection in the Light of the Microbiome. *Archives of Medical Research* 48(8): 780–789.
- Schaack, S. , Gilbert, C. and Feschotte, C. 2010. Promiscuous DNA: horizontal transfer of transposable elements and why it matters for eukaryotic evolution. *Trends in Ecology & Evolution* 25(9): 537–546.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Shapiro, J.A. 2017. Exploring the read-write genome: mobile DNA and mammalian adaptation. *Critical Reviews in Biochemistry and Molecular Biology* 52(1): 1–17.
- Shapiro, J.A. 2022. What we have learned about evolutionary genome change in the past 7 decades. *Biosystems* 215–216, 104669.
- Sharma, U. , Sun, F. , Conine, C.C. , Reichholf, B. , Kukreja, S. , Herzog, V.A. , ... Rando, O.J. 2018. Small RNAs Are Trafficked from the Epididymis to Developing Mammalian Sperm. *Developmental Cell*, 46(4): 481–494.e6.
- Sharon, G. , Segal, D. , Ringo, J.M. , Hefetz, A. , Zilber-Rosenberg, I. and Rosenberg, E. 2010. Commensal bacteria play a role in mating preference of *Drosophila melanogaster*. *Proceedings of the National Academy of Sciences*, 107(46): 20051–20056.
- Shropshire, J.D. and Bordenstein, S.R. 2016. Speciation by Symbiosis: the Microbiome and Behavior. *MBio* 7(2).
- Soucy, S.M. , Huang, J. and Gogarten, J.P. 2015. Horizontal gene transfer: building the web of life. *Nature Reviews Genetics* 16(8): 472–482.
- Stindl, R. 2014. The telomeric sync model of speciation: species-wide telomere erosion triggers cycles of transposon-mediated genomic rearrangements, which underlie the saltatory appearance of nonadaptive characters. *Naturwissenschaften* 101(3): 163–186.
- Stoeckle, M.Y. and Thaler, D.S. 2018. Why should mitochondria define species? *BioRxiv* 276717.
- Tauber, A.I. 2000. Moving beyond the immune self? *Seminars in Immunology* 12(3): 241–248.
- Templeton, A.R. 1998. Human Races: A Genetic and Evolutionary Perspective. *American Anthropologist* 100(3): 632–650.
- Thaler, D.S. 2021. Is Global Microbial Biodiversity Increasing, Decreasing, or Staying the Same? *Frontiers in Ecology and Evolution* 9(565649).
- Tonzo, V. , Papadopoulou, A. and Ortego, J. 2019. Genomic data reveal deep genetic structure but no support for current taxonomic designation in a grasshopper species complex. *Molecular Ecology* 28(17): 3869–3886.
- Torday, J.S. and Miller, W.B. 2016. Phenotype as Agent for Epigenetic Inheritance. *Biology* 5(3): 30.
- Torday, J.S. and Miller, W.B. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology* Cham, Switzerland: Springer.
- Villarreal, L.P. and Ryan, F. 2018. Viruses in the Origin of Life and Its Subsequent Diversification. In: *Handbook of Astrobiology*. Boca Raton, Florida, United States: CRC Press.
- Wang, T. , Zeng, J. , Lowe, C.B. , Sellers, R.G. , Salama, S.R. , Yang, M. , ... Haussler, D. 2007. Species-specific endogenous retroviruses shape the transcriptional network of the human tumor suppressor protein p53. *Proceedings of the National Academy of Sciences* 104(47):

18613–18618.

Wellenreuther, M. , Mérot, C. , Berdan, E. and Bernatchez, L. 2019. Going beyond SNPs: The role of structural genomic variants in adaptive evolution and species diversification. *Molecular Ecology* 28(6): 1203–1209.

Williams, G.C. and Nesse, R.M. 1991. The Dawn of Darwinian Medicine. *The Quarterly Review of Biology* 66(1): 1–22.

Witzany, G. 2011. Natural genome editing from a biocommunicative perspective. *Biosemiotics* 4(3): 349–368.

Witzany, G. 2014. Language and Communication as Universal Requirements for Life. pp. 349–369. In: V.M. Kolb (ed.). *Astrobiology: An Evolutionary Approach*. Boca Raton, Florida, United States: CRC Press.

## **Sexual Reproduction and its Impact on Evolutionary Variation**

Barton, N.H. and Charlesworth, B. 1998. Why sex and recombination?. *Science* 281(5385): 1986–1990.

Bateman, A.J. 1948. Intra-sexual selection in *Drosophila*. *Heredity* 2(3): 349–368.

Brussaard, C.P.D. 2004. Viral Control of Phytoplankton Populations—a Review. *The Journal of Eukaryotic Microbiology* 51(2): 125–138.

Carroll, L. (2010; 1871). *Through the looking glass and what Alice found there*. London: Penguin.

Crkvenjakov, R. and Heng, H.H. 2021. Further illusions: On key evolutionary mechanisms that could never fit with Modern Synthesis. *Progress in Biophysics and Molecular Biology* 169–170: 3–11.

Crow, J.F. 1994. Advantages of sexual reproduction. *Developmental Genetics* 15(3): 205–213.

Dixit, P.D. , Pang, T.Y. and Maslov, S. 2017. Recombination-Driven Genome Evolution and Stability of Bacterial Species. *Genetics* 207(1): 281–295.

Fontaneto, D. , Herniou, E.A. , Boschetti, C. , Caprioli, M. , Melone, G. , Ricci, C. and Barraclough, T.G. 2007. Independently Evolving Species in Asexual Bdelloid Rotifers. *PLoS Biology* 5(4): e87.

Garg, K.M. , Chattopadhyay, B. , Doss, D. P. S. , Ak, V. K. , Kandula, S. and Ramakrishnan, U. 2012. Promiscuous mating in the harem-roosting fruit bat, *Cynopterus sphinx*. *Molecular Ecology* 21(16): 4093–4105.

Gorelick, R. and Heng, H.H.Q. 2011. Sex Reduces Genetic Variation: A Multidisciplinary Review. *Evolution: International Journal of Organic Evolution* 65(4): 1088–1098.

Hersch-Green, E.I. , Myburg, H. and Johnson, M.T.J. 2012. Adaptive molecular evolution of a defence gene in sexual but not functionally asexual evening primroses. *Journal of Evolutionary Biology* 25(8): 1576–1586.

Jokela, J. , Dybdahl, M.F. and Lively, C.M. 2009. The Maintenance of Sex, Clonal Dynamics, and Host-Parasite Coevolution in a Mixed Population of Sexual and Asexual Snails. *The American Naturalist* 174(S1): S43–S53.

Jones, D.R. 2007. Disease And Pest Constraints To Banana Production. *Acta Horticulturae* (828): 21–36.

Krimsky, S. 2021. *Understanding DNA Ancestry*. Cambridge, England: Cambridge University Press.

Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.

Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.

Miller, W.B. and Torday, J.S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49–73.

Miller, W.B. , Torday, J.S. and Baluška, F. 2020. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112–139.

- Mordecai, G. , Verret, F. , Highfield, A. and Schroeder, D. 2017. Schrödinger's Cheshire Cat: Are Haploid *Emiliana huxleyi* Cells Resistant to Viral Infection or Not? *Viruses* 9(3): 51.
- Morin, P.J. 2008. Sex as an algal antiviral strategy. *Proceedings of the National Academy of Sciences* 105(41), 15639–15640.
- Morran, L.T. , Schmidt, O.G. , Gelarden, I.A. , Parrish, R.C. and Lively, C.M. 2011. Running with the Red Queen: Host-Parasite Coevolution Selects for Biparental Sex. *Science* 333(6039): 216–218.
- Moseley, H.N. 1886. Dr. August Weismann on the Importance of Sexual Reproduction for the theory of Selection 1. *Nature* 34(887): 629–632.
- Natterson-Horowitz, B. and Bowers, K. 2012. *Zoobiquity: What animals can teach us about health and the Science of Healing*. Knopf, New York: Penguin Random House
- Otto, S.P. 2008. Sexual Reproduction and the Evolution of Sex. *Nature Education* 1(1): 182.
- Péllissié, B. , Jarne, P. , Sarda, V. and David, P. 2014. Disentangling Precopulatory And Postcopulatory Sexual Selection In Polyandrous Species. *Evolution* 68(5): 1320–1331.
- Poinar, G.O. and Ricci, C. 1992. Bdelloid rotifers in Dominican amber: Evidence for parthenogenetic continuity. *Experientia* 48(4): 408–410.
- Reusch, T.B.H. , Baums, I.B. and Werner, B. 2021. Evolution via somatic genetic variation in modular species. *Trends in Ecology & Evolution* 36(12): 1083–1092.
- Tang-Martínez, Z. 2016. Rethinking Bateman's Principles: Challenging Persistent Myths of Sexually Reluctant Females and Promiscuous Males. *The Journal of Sex Research*, 53(4–5): 532–559.
- Torday, J. and Miller, W. 2016. The Unicellular State as a Point Source in a Quantum Biological System. *Biology* 5(2): 25.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Valen, L. Van . 1973. A new evolutionary law. *Evolution Theory* 1: 1–30.

## Chapter 15 Extinction

- Agnolin, F.L. , Powell, J.E. , Novas, F.E. and Kundrát, M. 2012. New alvarezsaurid (Dinosauria, Theropoda) from uppermost Cretaceous of north-western Patagonia with associated eggs. *Cretaceous Research* 35: 33–56.
- Bakker, R.T. 1986. *The Dinosaur Heresies: New Theories Unlocking the Mystery of the Dinosaurs and Their Extinction*. New York City, Ny, USA: William Morrow.
- Bermejo, M. , Rodríguez-Teijeiro, J.D. , Illera, G. , Barroso, A. , Vilà, C. and Walsh, P.D. 2006. Ebola Outbreak Killed 5000 Gorillas. *Science* 314(5805): 1564.
- Bianchine, P.J. and Russo, T.A. 1992. The Role of Epidemic Infectious Diseases in the Discovery of America. *Allergy and Asthma Proceedings* 13(5): 225–232.
- Blehert, D.S. , Hicks, A.C. , Behr, M. , Meteyer, C.U. , Berlowski-Zier, B.M. , Buckles, E.L. , ... Stone, W.B. . 2009. Bat White-Nose Syndrome: An Emerging Fungal Pathogen? *Science* 323(5911): 227.
- Brusatte, S.L. , Butler, R.J. , Barrett, P.M. , Carrano, M.T. , Evans, D.C. , Lloyd, G.T. , ... Williamson, T.E. 2015. The extinction of the dinosaurs. *Biological Reviews* 90(2): 628–642.
- Congreve, C.R. , Falk, A.R. and Lamsdell, J.C. 2018. Biological hierarchies and the nature of extinction. *Biological Reviews* 93(2): 811–826.
- Cowie, R.H. , Bouchet, P. and Fontaine, B. 2022. The Sixth Mass Extinction: fact, fiction or speculation? *Biological Reviews* 97(2): 640–663.
- Coyne, J.A. and Orr, H.A. 2004. *Speciation*. Sunderland, MA: Sinauer Associates.
- Diamond, J. 1997. *Guns, Germs, and Steel: The Fates of Human Societies*. New York: W.W. Norton & Company.
- Erwin, D.H. 2006. *How life on earth nearly ended 250 million years ago*. Princeton, New Jersey: Princeton University Press.
- Friedman, A. and Yakubu, A.-A. 2012. Fatal disease and demographic Allee effect: population persistence and extinction. *Journal of Biological Dynamics* 6(2): 495–508.

- Fritts, T.H. and Rodda, G.H. 1998. The Role Of Introduced Species In: The Degradation Of Island Ecosystems: A Case History Of Guam. *Annual Review of Ecology and Systematics* 29(1): 113–140.
- Jaffe, A.C. 2011. Failure to Thrive: Current Clinical Concepts. *Pediatrics in Review* 32(3): 100–108.
- Keller, G. , Abramovich, S. , Berner, Z. and Adatte, T. 2009. Biotic effects of the Chicxulub impact, K–T catastrophe and sea level change in Texas. *Palaeogeography, Palaeoclimatology, Palaeoecology* 271(1–2): 52–68.
- Kerr, P.J. and Best, S.M. 1998. Myxoma virus in rabbits. *Revue Scientifique et Technique de l'OIE* 17(1): 256–268.
- Kirschner, M.W. and Gerhart, J.C. 2005. *The Plausibility of Life: Resolving Darwin's Dilemma*. New Haven: Yale University Press.
- Lamkin, M. and Miller, A.I. 2016. On the Challenge of Comparing Contemporary and Deep-Time Biological-Extinction Rates. *BioScience* 66(9): 785–789.
- Larson-Nath, C. and Biank, V.F. 2016. Clinical Review of Failure to Thrive in Pediatric Patients. *Pediatric Annals*, 45(2).
- Lawton, J.H. and May, R.M. . (eds.). (1995). *Extinction rates* (Vol. 11). Oxford: Oxford University Press.
- MacPhee, R.D.E. and Marx, P.A. 1997. The 40,000-Year Plague: Humans, Hyperdisease, and First-Contact Extinctions. pp. 169–217. In: S.M. Goodman and B.D. Patterson (eds.). *Natural Change and Human Impact in Madagascar*. Washington D.C.: Smithsonian Institution Scholarly Press.
- MacPhee, R.D.E. and Marx, P.A. 1998. *Lightning Strikes Twice: Blitzkrieg, Hyperdisease, and Global Explanations of the Late Quaternary Catastrophic Extinctions*. American Museum of Natural History.
- Martini, M. , Gazzaniga, V. , Bragazzi, N.L. and Barberis, I. 2019. The Spanish Influenza Pandemic: A lesson from history 100 years after 1918. *Journal of Preventive Medicine and Hygiene* 60(1): E64–E67.
- McEwen, G.K. , Alquezar-Planas, D.E. , Dayaram, A. , Gillett, A. , Tarlinton, R. , Mongan, N. , ... Greenwood, A.D. 2021 Retroviral integrations contribute to elevated host cancer rates during germline invasion. *Nature Communications* 12(1): 1316.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Monastersky, R. 1999. The Killing Fields. *Science News*, 156(23): 360–361.
- Perlman, S.J. and Jaenike, J. 2003. Infection Success In Novel Hosts: An Experimental And Phylogenetic Study of *Drosophila*-Parasitic Nematodes. *Evolution* 57(3): 544–557.
- Poinar Jr., G. and Poinar, R. 2007. *What Bugged the Dinosaurs?: Insects, Disease, and Death in the Cretaceous* (Illustrate). Princeton: Princeton University Press.
- Racki, G. 2015. Catastrophism And Neocatastrophism Versus Cosmic Hazard: Ager Versus Alvarez; Cuvier Versus Laplace. *Palaios* 30(6): 443–445.
- Raup, D.M. 1991. A kill curve for Phanerozoic marine species. *Paleobiology* 17(1): 37–48.
- Raup, D.M. 1992. *Extinction: Bad Genes or Bad Luck?* New York City, Ny, USA: WW Norton & Company.
- Renne, P.R. , Deino, A.L. , Hilgen, F.J. , Kuiper, K.F. , Mark, D.F. , Mitchell, W.S. , ... Smit, J. 2013. Time Scales of Critical Events Around the Cretaceous-Paleogene Boundary. *Science* 339(6120): 684–687.
- Sarkesh, A. , Sorkhabi, A.D. , Ahmadi, H. , Abdolmohammadi-Vahid, S. , Parhizkar, F. , Yousefi, M. and Aghebati-Maleki, L. 2022. Allogeneic lymphocytes immunotherapy in female infertility: Lessons learned and the road ahead. *Life Sciences* 299: 120503.
- Schommer, T.J. and Woolever, M.M. 2008. A review of disease related conflicts between domestic sheep and goats and bighorn sheep. *Gen. Tech. Rep. RMRS-GTR-209* Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Simmons, G. , Young, P. , Hanger, J. , Jones, K. , Clarke, D. , McKee, J. and Meers, J. 2012. Prevalence of koala retrovirus in geographically diverse populations in Australia. *Australian Veterinary Journal*, 90(10): 404–409.
- Spraker, T.R. , Hibler, C.P. , Schoonveld, G.G. and Adney, W.S. 1984. Pathologic Changes and Microorganisms Found In Bighorn Sheep During A Stress-Related Die-Off. *Journal of Wildlife*

Diseases 20(4): 319–327.

Thogmartin, W.E. , Sanders-Reed, C.A. , Szymanski, J.A. , McKann, P.C. , Pruitt, L. , King, R.A. , ... Russell, R.E. 2013. White-nose syndrome is likely to extirpate the endangered Indiana bat over large parts of its range. *Biological Conservation* 160: 162–172.

Thornton, R. 1987. *American Indian Holocaust and Survival: A Population History since 1492*. Norman, Oklahoma: University of Oklahoma Press.

Van Valen, L. 1973. A new evolutionary law. *Evolution Theory* 1: 1–30.

Venzon, M. , Das, R. , Luciano, D.J. , Burnett, J. , Park, H.S. , Devlin, J.C. , ... Cadwell, K. 2022. Microbial byproducts determine reproductive fitness of free-living and parasitic nematodes. *Cell Host & Microbe* 30(6): 786–797.e8.

Wake, D.B. 2012. Facing Extinction in Real Time. *Science* 335(6072): 1052–1053.

Werren, J.H. 2003. Invasion of the Gender Benders: by manipulating sex and reproduction in their hosts, many parasites improve their own odds of survival and may shape the evolution of sex itself. *Natural History* 112(1): 58.

Wiens, D. , Allphin, L. , Wall, M. , Slaton, M.R. and Davis, S.D. 2012. Population decline in *Adenostoma sparsifolium* (Rosaceae): an ecogenetic hypothesis for background extinction†. *Biological Journal of the Linnean Society* 105(2): 269–292.

Wiens, D. , Sweet, T. and Worsley, T. 2020. Validating the New Paradigm for Extinction: Overcoming 200 Years of Historical Neglect, Philosophical Misconception, and Inadequate Language. *The Quarterly Review of Biology* 95(2): 109–124.

Wiens, D. and Worsley, T. 2016. Reproductive failure: a new paradigm for extinction. *Biological Journal of the Linnean Society* 119(4): 1096–1102.

Willis, K.J. and Bennett, K.D. 1995. Mass extinction, punctuated equilibrium and the fossil plant record. *Trends in Ecology & Evolution* 10(8): 308–309.

Wolff, E.D.S. , Salisbury, S.W. , Horner, J.R. and Varricchio, D.J. 2009. Common Avian Infection Plagued the Tyrant Dinosaurs. *PLoS ONE* 4(9): e7288.

Wyatt, K.B. , Campos, P.F. , Gilbert, M.T.P. , Kolokotronis, S.-O. , Hynes, W.H. , DeSalle, R. , ... Greenwood, A.D. 2008. Historical Mammal Extinction on Christmas Island (Indian Ocean) Correlates with Introduced Infectious Disease. *PLoS ONE* 3(11): e3602.

## Old Controversies Revisited Where is the Cusp of Creativity?

Agnati, L.F. , Baluška, F. , Barlow, P.W. and Guidolin, D. 2009. Mosaic, self-similarity logic and biological attraction principles. *Communicative & Integrative Biology* 2(6): 552-563.

Avery, M.E. and Mead, J. 1959. Surface Properties in Relation to Atelectasis and Hyaline Membrane Disease. *Archives of Pediatrics & Adolescent Medicine* 97(5 PART I): 517-523.

Bak, P. , Tang, C. and Wiesenfeld, K. 1987. Self-organized criticality: An explanation of the 1/f noise. *Physical Review Letters* 59(4): 381-384.

Baluška, F. and Lyons, S. 2018a. Energide-cell body as smallest unit of eukaryotic life. *Annals of Botany* 122(5): 741-745.

Baluška, F. and Lyons, S. 2018b. Symbiotic Origin of Eukaryotic Nucleus: From Cell Body to Neo-Energide. pp. 39-66. *In: V.P. Sahi and F. Baluška (eds.). Concepts in Cell Biology-History and Evolution*. Cham, Switzerland: Springer.

Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.

Cabin, Z. , Derieg, N.J. , Garton, A. , Ngo, T. , Quezada, A. , Gasseholm, C. , ... Hodges, S.A. 2022. Non-pollinator selection for a floral homeotic mutant conferring loss of nectar reward in *Aquilegia coerulea*. *Current Biology* 32(6): 1332-1341.e5.

Chen, H. , Lin, F. , Xing, K. and He, X. 2015. The reverse evolution from multicellularity to unicellularity during carcinogenesis. *Nature Communications* 6(1): 1-10.

Collins, S. , Boyd, P.W. and Doblin, M.A. 2020. Evolution, Microbes, and Changing Ocean Conditions. *Annual Review of Marine Science* 12: 181-208.

Daniels, C.B. and Orgeig, S. 2003. Pulmonary Surfactant: The Key to the Evolution of Air Breathing. *Physiology* 18(4): 151-157.

Dixit, P.D. , Pang, T.Y. and Maslov, S. 2017. Recombination-Driven Genome Evolution and Stability of Bacterial Species. *Genetics* 207(1): 281-295.

Dollo, L. 1893. The Laws of Evolution. Extract from the Bulletin de La Societe Belge de Geologic de Paléontologic & D'Hydrologie 7: 164-166.

Fontenele, A.J. , de Vasconcelos, N.A.P. , Feliciano, T. , Aguiar, L.A.A. , Soares-Cunha, C. , Coimbra, B. , Copelli, M. 2019. Criticality between Cortical States. *Physical Review Letters* 122(20): 208101.

Forni, G. , Martellosi, J. , Valero, P. , Hennemann, F.H. , Conle, O. , Luchetti, A. and Mantovani, B. 2021. Macroevolutionary Analyses Provide New Evidence of Phasmid Wings Evolution as a Reversible Process. *Systematic Biology*.

Fosque, L.J. , Williams-García, R.V. , Beggs, J.M. and Ortiz, G. 2021. Evidence for Quasicritical Brain Dynamics. *Physical Review Letters* 126(9): 098101.

Freed, L.A. , Medeiros, M.C.I. and Cann, R.L. 2016. Multiple Reversals of Bill Length over 1.7 Million Years in a Hawaiian Bird Lineage. *The American Naturalist* 187(3): 363-371.

Futuyma, D.J. 2010. Evolutionary Constraint And Ecological Consequences. *Evolution: International Journal of Organic Evolution* 64(7): 1865-1884.

Gould, S.J. 1977. The Return of Hopeful Monsters. *Natural History* 86(June/July): 22-30.

Gould, S.J. and Eldredge, N. 1972. Punctuated equilibria: an alternative to phyletic gradualism. *Models in paleobiology* 1972: 82-115.

Graham, T.A. and Sottoriva, A. 2017. Measuring cancer evolution from the genome. *The Journal of Pathology* 241(2): 183-191.

Guex, J. 2016. *Retrograde Evolution During Major Extinction Crises*. Heidelberg: Springer.

Guex, J. , S. Torday , J. Miller and Miller, W.B. (eds.). 2020. *Morphogenesis, Environmental Stress and Reverse Evolution*. Cham: Springer.

Gunnell, G.F. and Simmons, N.B. 2005. Fossil Evidence and the Origin of Bats. *Journal of Mammalian Evolution* 12(1-2): 209-246.

Hankey, A. 2018. A Mathematical Model of Free Will Based on Experience Information in a Quantum Universe. pp. 549-556. In: *Unified Field Mechanics II: Formulations and Empirical Tests*. World Scientific.

Heasley, L.R. , Sampaio, N.M.V. and Argueso, J.L. 2021. Systemic and rapid restructuring of the genome: a new perspective on punctuated equilibrium. *Current Genetics* 67(1): 57-63.

Hendry, A.P. 2016. Key Questions on the Role of Phenotypic Plasticity in Eco-Evolutionary Dynamics. *Journal of Heredity* 107(1): 25-41.

Hodgkin, J. 1998. Seven types of pleiotropy. *The International Journal of Developmental Biology* 42(3): 501-505.

Irie, N. and Kuratani, S. 2011. Comparative transcriptome analysis reveals vertebrate phylotypic period during organogenesis. *Nature Communications* 2(248).

Jacobs, D.K. , Hughes, N.C. , Fitz-Gibbon, S.T. and Winchell, C.J. 2005. Terminal addition, the Cambrian radiation and the Phanerozoic evolution of bilaterian form. *Evolution & Development* 7(6): 498-514.

Jacob, F. 1977. Evolution and Tinkering. *Science* 196(4295): 1161-1166.

Jiggins, F.M. and Hurst, G.D.D. 2011. Rapid Insect Evolution by Symbiont Transfer. *Science* 332(6026): 185-186.

Kriegman, S. , Cheney, N. and Bongard, J. 2018. How morphological development can guide evolution. *Scientific Reports* 8: 13934.

Lenski, R.E. and Travisano, M. 1994. Dynamics of adaptation and diversification: a 10,000-generation experiment with bacterial populations. *Proceedings of the National Academy of Sciences* 91(15): 6808-6814.

Levit, G.S. , HoBfeld, U. , Naumann, B. , Lukas, P. and Olsson, L. 2022. The biogenetic law and the Gastraea theory: From Ernst Haeckel's discoveries to contemporary views. *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution* 338(1-2): 13-27.

Lockwood, J.A. 2005. *Locust: The Devastating Rise and Mysterious Disappearance of the Insect that Shaped the American Frontier*. New York: Basic Books.

Margulis, L. 1971. Symbiosis and Evolution. *Scientific American* 225(2): 48-57.

Matsuno, K. 2017. From quantum measurement to biology via retrocausality. *Progress in Biophysics and Molecular Biology* 131: 131-140.

McClintock, B. 1984. The Significance of Responses of the Genome to Challenge. *Science* 226(4676): 792-801.

- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular senomic measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. and Torday, J. S. 2018. Four domains: The fundamental unicell and Post-Darwinian Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 140: 49-73.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Murren, C.J. , Auld, J.R. , Callahan, H. , Ghalambor, C.K. , Handelsman, C.A. , Heskell, M.A. , ... Schlichting, C.D. 2015. Constraints on the evolution of phenotypic plasticity: limits and costs of phenotype and plasticity. *Heredity* 115(4): 293-301.
- Noble, D. 2021. Cellular Darwinism: Regulatory networks, stochasticity, and selection in cancer development. *Progress in Biophysics and Molecular Biology* 165: 66-71.
- Olsson, L. , Levit, G.S. and Hoßfeld, U. 2017. The “Biogenetic Law” in zoology: from Ernst Haeckel’s formulation to current approaches. *Theory in Biosciences* 136(1-2): 19-29.
- Ozment, E. , Tamvacakis, A.N. , Zhou, J. , Rosiles-Loeza, P.Y. , Escobar-Hernandez, E.E. , Fernandez-Valverde, S.L. and Nakanishi, N. 2021. Cnidarian hair cell development illuminates an ancient role for the class IV POU transcription factor in defining mechanoreceptor identity. *ELife*, 10.
- Recknagel, H. , Kamenos, N.A. and Elmer, K.R. 2018. Common lizards break Dollo’s law of irreversibility: Genome-wide phylogenomics support a single origin of viviparity and re-evolution of oviparity. *Molecular Phylogenetics and Evolution* 127: 579-588.
- Romer, A.S. 1949. *The Vertebrate Story*. Chicago: University of Chicago Press.
- Ryckman, L.L. 1999. *The Great Locust Mystery*. Rocky Mountain News. Archived from the Original on February 28, 2007.
- Schneider, R.F. and Meyer, A. 2017. How plasticity, genetic assimilation and cryptic genetic variation may contribute to adaptive radiations. *Molecular Ecology* 26(1): 330-350.
- Shakbnovich, B.E. and Koonin, E.V. 2006. Origins and impact of constraints in evolution of gene families. *Genome Research* 16(12): 1529-1536.
- Shapiro, J.A. 2022. What we have learned about evolutionary genome change in the past 7 decades. *Biosystems* 215-216: 104669.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Stebbins Jr., G.L. 1951. Cataclysmic Evolution. *Scientific American* 184(4): 54-59.
- Thisse, B. and Thisse, C. 2015. Formation of the vertebrate embryo: Moving beyond the Spemann organizer. *Seminars in Cell & Developmental Biology* 42: 94-102.
- Torday, J. 2016. The Cell as the First Niche Construction. *Biology* 5(2): 19.
- Torday, J. and Miller, W. 2016a. Phenotype as Agent for Epigenetic Inheritance. *Biology* 5(3): 30.
- Torday, J.S. and Miller, W.B. 2016b. The Unicellular State as a Point Source in a Quantum Biological System. *Biology* 5(2): 25.
- Torday, J.S. and Miller, W.B. 2018a. Terminal addition in a cellular world. *Progress in Biophysics and Molecular Biology* 135: 1-10.
- Torday, J.S. and Miller, W.B. 2018b. A systems approach to physiologic evolution: From micelles to consciousness. *Journal of Cellular Physiology* 233(1): 162-167.
- Torday, J.S. and Miller, Jr, W.B. 2018c. Unitary Physiology. *Comprehensive Physiology* 8(2): 761-771.
- Torday, J. and Miller, W. 2020a. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Torday, J.S. and Miller Jr., W.B. 2020b. *The Singularity of Nature: A Convergence of Biology, Chemistry and Physics*. United Kingdom: Royal Society of Chemistry.
- Torday, J.S. and Rehan, V. K. 2002. *Mechanotransduction Determines the Structure and Function of Lung and Bone : A Theoretical Model for the Pathophysiology of Chronic Disease*. *Cell Biochemistry and Biophysics* 37(3): 235-246.

- Torday, J.S. and Rehan, V.K. 2007. The evolutionary continuum from lung development to homeostasis and repair. *American Journal of Physiology-Lung Cellular and Molecular Physiology* 292(3): L608-L611.
- Torday, J.S. and Rehan, V.K. 2011. A Cell-Molecular Approach Predicts Vertebrate Evolution. *Molecular Biology and Evolution* 28(11): 2973-2981.
- Wagner, A.M. 2008. Grasshoppered: America's Response to the 1874 Rocky Mountain Locust Invasion. *Nebraska History* 89: 154-167.

## The Primacy of Cellular Consciousness

- Annunziata, R. , Mele, B.H. , Marotta, P. , Volpe, M. , Entrambasaguas, L. , Mager, S. , ... Ferrante, M.I. 2022. Trade-off between sex and growth in diatoms: Molecular mechanisms and demographic implications. *Science Advances* 8(3).
- Baluška, F. and Miller, Jr, W.B. 2018. Senomic view of the cell: Senome versus Genome. *Communicative & Integrative Biology* 11(3): 1-9.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2022. Cellular and evolutionary perspectives on organismal cognition: from unicellular to multicellular organisms. *Biological Journal of the Linnean Society* (blac005).
- Baluška, F. and Reber, A. 2019. Sentience and Consciousness in Single Cells: How the First Minds Emerged in Unicellular Species. *BioEssays* 41(3): 1800229.
- Baluška, F. and Reber, A.S. 2021. The Biomolecular Basis for Plant and Animal Sentience: Senomic and Ephaptic Principles of Cellular Consciousness. *Journal of Consciousness Studies* 28(1-2): 31-49.
- Baluška, F. , Reber, A.S. and Miller, W.B. 2022. Cellular sentience as the primary source of biological order and evolution. *Biosystems* 218: 104694.
- Boly, M. , Seth, A.K. , Wilke, M. , Ingmundson, P. , Baars, B. , Laureys, S. , ... Tsuchiya, N. 2013. Consciousness in humans and non-human animals: recent advances and future directions. *Frontiers in Psychology* 4(625).
- Cárdenas-García, J.F. 2020. The Process of Info-Autopoiesis -the Source of all Information. *B osem ot cs* 13(2): 199-221.
- Chalmers, D.D. 1995. Facing Up to the Problem of Consciousness. *Journal of Consciousness Studies* 2(3): 200-219.
- Constant, A. , Ramstead, M.J.D. , Veissiere, S.P.L. , Campbell, J.O. and Friston, K.J. 2018. A variational approach to niche construction. *Journal of The Royal Society Interface* 15(141): 20170685.
- Cooke, J.E. 2021. What Is Consciousness? Integrated Information vs. Inference. *Entropy* 23(8): 1032.
- Darwin, C. 2008. *The Descent of Man, and Selection in Relation to Sex*. Princeton, New Jersey, USA: Princeton University Press.
- Fields, C. , Glazebrook, J.F. and Levin, M. 2021. Minimal physicalism as a scale-free substrate for cognition and consciousness. *Neuroscience of Consciousness* 2021(2): niab013.
- Fitch, W.T. 2008. Nano-intentionality: a defense of intrinsic intentionality. *Biology & Philosophy* 23(2): 157-177.
- Friston, K. 2017. The mathematics of mind-time. *Aeon magazine*.
- Friston, K. , Kilner, J. and Harrison, L. 2006. A free energy principle for the brain. *Journal of Physiology-Paris* 100(1-3): 70-87.
- Friston, K. , Mattout, J. and Kilner, J. 2011. Action understanding and active inference. *Biological Cybernetics* 104(1-2): 137-160.
- Fuchs, T. 2012. *Feelings of Being Alive*. pp. 149-165. *In: J. Fingerhut and S. Marienberg (eds.). Feelings of being Alive*. Berlin, Germany: De Gruyter.
- Hodassman, S. , Meir, Y. , Kisos, K. , Ben-Noam, I. , Tugendhaft, Y. , Goldental, A. , ... and Kanter, I. 2022. Brain inspired neuronal silencing mechanism to enable reliable sequence identification. *Scientific Reports* 12: 16003.

- Hameroff, S. 2007. Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness. *NeuroQuantology* 5(1).
- Klein, C. and Barron, A.B. 2016. Insects have the capacity for subjective experience. *Animal Sentience* 1(9).
- Lieff, J. 2020. *The Secret Language of Cells: What Biological Conversations Tell Us About the Brain-Body Connection, the Future of Medicine, and Life Itself*. Texas: Ben Bella Books.
- Marshall, P. 2021. Biology transcends the limits of computation. *Progress in Biophysics and Molecular Biology* 165: 88-101.
- Mashour, G.A. and Andre, M.T. 2013. Evolution of consciousness: Phylogeny, ontogeny, and emergence from general anesthesia. *Proceedings of the National Academy of Sciences* 110(supplement 2): 10357-10364.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020b. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020a. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Niikawa, T. , Hayashi, Y. , Shepherd, J. and Sawai, T. 2022. Human Brain Organoids and Consciousness. *Neuroethics* 15(1): 5.
- Oizumi, M. , Albantakis, L. and Tononi, G. 2014. From the Phenomenology to the Mechanisms of Consciousness: Integrated Information Theory 3.0. *PLoS Computational Biology* 10(5): e1003588.
- Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York, NY, USA: Oxford University Press.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Simeonov, P.L. and Ehresmann, A.C. 2017. Some resonances between Eastern thought and Integral Biomathics in the framework of the WLIMES formalism for modeling living systems. *Progress in Biophysics and Molecular Biology* 131: 193-212.
- Theiner, G. , Allen, C. and Goldstone, R.L. 2010. Recognizing group cognition. *Cognitive Systems Research* 11(4): 378-395.
- Tilot, A.K. , Vino, A. , Kucera, K.S. , Carmichael, D.A. , van den Heuvel, L. , den Hoed, J. , ... Fisher, S. E. (2019). Investigating genetic links between grapheme-colour synaesthesia and neuropsychiatric traits. *Philosophical Transactions of the Royal Society B: Biological Sciences* 374(1787): 20190026.
- Timsit, Y. and Grégoire, S.-P. 2021. Towards the Idea of Molecular Brains. *International Journal of Molecular Sciences* 22(21): 11868.
- Tollefsen, D.P. 2006. From extended mind to collective mind. *Cognitive Systems Research* 7(2-3): 140-150.
- Tononi, G. 2004. An Information Integration Theory of Consciousness. *BMC Neuroscience* 5(42): 1-22.
- Tononi, G. 2008. Consciousness as Integrated Information: a Provisional Manifesto. *The Biological Bulletin* 215(3): 216-242.
- Torday, J. and Miller, W. 2016. Phenotype as Agent for Epigenetic Inheritance. *Biology* 5(3): 30.

## How Might Biology Instruct Physics?

- Akama, K. 2014. A Universal Origin of Information Accumulation in Nature arXiv preprint. ArXiv 1408.6201.
- Baluška, F. , Miller, W.B. and Reber, A.S. 2021. Biomolecular Basis of Cellular Consciousness via Subcellular Nanobrain. *International Journal of Molecular Sciences* 22(5): 2545.

Baluška, F. , Reber, A.S. and Miller, W.B. 2022. Cellular sentience as the primary source of biological order and evolution. *Biosystems* 218: 104694.

Bohm, D.J. and Hiley, B.J. 1975. On the intuitive understanding of nonlocality as implied by quantum theory. *Foundations of Physics* 5(1): 93-109.

Cárdenas-García, J.F. 2020. The Process of Info-Autopoiesis-the Source of all Information. *Biosemiotics* 13(2): 199-221.

Castelvecchi, D. 2016. People can sense single photons. *Nature*.

Chopra, D. and Kafatos, M.C. 2017. *You Are the Universe: Discovering Your Cosmic Self and Why It Matters* (Reprint). New York: Harmony.

Clement, W.C. 1953. Russell's Structuralist Thesis. *The Philosophical Review* 62(2): 266.

De Loof, A. 2017. The evolution of "Life": A Metadarwinian integrative approach. *Communicative & Integrative Biology* 10(3): e1301335.

Dodig-Crnkovic, G. 2013. Alan Turing's Legacy: Info-computational Philosophy of Nature. pp. 115-123. In: G. Dodig-Crnkovic and R. Giovagnoli (eds.). *Computing Nature*. Berlin, Heidelberg: Springer.

Eddington, S.A. 1939. *The Philosophy of Physical Science: Tamer Lectures (1938)*. CUP Archive. Cambridge, UK: Cambridge University Press.

Fields, C. , Glazebrook, J.F. and Levin, M. 2022. Neurons as hierarchies of quantum reference frames. *Biosystems* 219: 104714.

Fuchs, C.A. 2011. *Coming of Age With Quantum Information: Notes on a Paulian Idea*. Cambridge, UK: Cambridge University Press.

Gefter, A. 2015. A Private View of Quantum Reality. Retrieved from <https://www.quantamagazine.org/quantum-bayesianism-explained-by-its-founder-20150604/>

Giacomini, F. , Castro-Ruiz, E. and Brukner, C. 2019. Quantum mechanics and the covariance of physical laws in quantum reference frames. *Nature Communications* 10: 494.

Griffin, D.R. 1985. Bohm And Whitehead On Wholeness, Freedom, Causality, And Time. *Zygon* 20(2): 165-191.

Gunji, Y.-P. , Sonoda, K. and Basios, V. 2016. Quantum cognition based on an ambiguous representation derived from a rough set approximation. *Biosystems* 141: 55-66.

Igamberdiev, A.U. and Shklovskiy-Kordi, N.E. 2017. The quantum basis of spatiotemporality in perception and consciousness. *Progress in Biophysics and Molecular Biology* 130: 15-25.

Kafatos, M.C. 2014. Physics and consciousness: quantum measurement, observation and experience. *Frontiers in Consciousness Research* 4: 1-14.

Khrennikov, A. 2007. Can Quantum Information be Processed by Macroscopic Systems? *Quantum Information Processing* 6(6): 401-429.

Kirchhoff, M. , Parr, T. , Palacios, E. , Friston, K. and Kiverstein, J. 2018. The Markov blankets of life: autonomy, active inference and the free energy principle. *Journal of The royal society interface* 15(138): 20170792.

Lohrey, A. and Boreham, B. 2021. Lifting the veil on Bohm's holomovement. *Communicative & Integrative Biology* 14(1): 221-229.

Longo, G. and Montévil, M. 2011. From physics to biology by extending criticality and symmetry breakings. *Progress in Biophysics and Molecular Biology* 106(2): 340-347.

Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.

Miller, W.B. , Baluška, F. and Torday, J.S. 2020b. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.

Miller, W.B. , Baluška, F. and Reber, A.S. 2022. A scale-free universal relational information matrix (N-space) reconciles the information problem: N-space as the fabric of reality. Submitted.

Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54-74.

Miller, W.B. , Torday, J.S. and Baluška, F. 2020a. The N-space Epigenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.

Nagel, T. 2012. *Mind & Cosmos: Why the Materialist Neo-Darwinian Conception of Nature is Almost Certainly False*. Oxford, UK: Oxford University Press.

Palacios, E.R. , Razi, A. , Parr, T. , Kirchhoff, M. and Friston, K. 2020. On Markov blankets and hierarchical self-organisation. *Journal of Theoretical Biology* 486 : 110089.

- Rosen, S.M. 2021. The Strange Nature of Quantum Perception: To See a Photon, One Must Be a Photon. *The Institute of Mind and Behavior, Inc. The Journal of Mind and Behavior* 42(3 & 4): 229-270.
- Rusu, B. (2011). *Whitehead and Green: The Metaphysics of Universal Relatedness*. *Chromatikon: Annales de La Philosophie En Proces/Yearbook of Philosophy in Process* 7: 169-201.
- Schroeder, M.J. 2017. The difference that makes a difference for the conceptualization of information. *Multidisciplinary Digital Publishing Institute Proceedings* 1(3): 221.
- Seager, W. 2018. The Philosophical and Scientific Metaphysics of David Bohm. *Entropy* 20(7): 493.
- Stonier, T. 1996. Information as a basic property of the universe. *Biosystems* 38(2-3): 135-140.
- Torday, J.S. and Miller, W.B. 2018. The Cosmologic continuum from physics to consciousness. *Progress in Biophysics and Molecular Biology* 140: 41-48.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Tozzi, A. and Peters, J.F. 2018. What is it like to be “the same”? *Progress in Biophysics and Molecular Biology* 133: 30-35.
- Whitehead, A.N. 1967. *Science and the Modern World*. New York: Free Press.
- Whitehead, A.N. 1985. *Symbolism: Its Meaning and Effect*. New York: Fordham University Press.
- Xin, H. , Sim, W.J. , Namgung, B. , Choi, Y. , Li, B. and Lee, L.P. 2019. Quantum biological tunnel junction for electron transfer imaging in live cells. *Nature Communications* 10(1): 3245.

## A Separation from the Past

- Adami, C. 2016. What is information? *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374(2063): 20150230.
- Arthur, W. 2004. *Biased Embryos and Evolution*. Cambridge , UK: Cambridge University Press.
- Baluška, F. 2009. Cell-Cell Channels, Viruses, and Evolution. *Annals of the New York Academy of Sciences* 1178(1): 106-119.
- Baluška, F. and Reber, A. 2019. Sentience and Consciousness in Single Cells: How the First Minds Emerged in Unicellular Species. *BioEssays* 41(3): 1800229.
- Ben-Jacob, E. 2009. Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences* 1178(1): 78-90.
- Ben-Jacob, E. and Levine, H. 2006. Self-engineering capabilities of bacteria. *Journal of The Royal Society Interface* 3(6): 197-214.
- Berry, R.S. 2019. *Three Laws of Nature: A Little Book on Thermodynamics*. New Haven: Yale University Press.
- Blackiston, D. , Lederer, E. , Kriegman, S. , Gamier, S. , Bongard, J. and Levin, M. 2021. A cellular platform for the development of synthetic living machines. *Science Robotics* 6(52).
- Corning, P.A. 2020. Beyond the modern synthesis: A framework for a more inclusive biological synthesis. *Progress in Biophysics and Molecular Biology* 153: 5-12.
- De Loof, A. (2015). Organic and Cultural Evolution can be Seamlessly Integrated Using the Principles of Communication and Problem-Solving: The Foundations for an Extended Evolutionary Synthesis (EES) as Outlined in the Mega-Evolution Concept. *Life: The Excitement of Biology* 2(4): 247-269.
- Dreze, M. , Charloreaux, B. , Milstein, S. , Vidalain, P.-O. , Yildirim, M. A. , Zhong, Q. , ... Vidal, M. 2009. “Edgetic” perturbation of a *C. elegans* BCL2 ortholog. *Nature Methods* 6(11): 843-849.
- Ford, B.J. 2004. Are Cells Ingenious? *Microscope* 52(3/4): 135-144.
- Ford, B.J. 2009. On Intelligence in Cells: The Case for Whole Cell Biology. *Interdisciplinary Science Reviews* 34(4): 350-365.
- Ford, B.J. 2017. Cellular intelligence: Microphenomenology and the realities of being. *Progress in Biophysics and Molecular Biology* 131: 273-287.
- Futo, M. , Opašić, L. , Koska, S. , Čorak, N. , Široki, T. , Ravikumar, V. , ... Domazet-Lošo, T. 2021. Embryo-Like Features in Developing *Bacillus subtilis* Biofilms. *Molecular Biology and*

- Evolution 38(1): 31-47.
- Goldenfeld, N. and Woese, C. 2007. Biology's next revolution. *Nature* 445(7126): 369-369.
- Goldenfeld, N. and Woese, C. 2011. Life is Physics: Evolution as a Collective Phenomenon Far From Equilibrium. *Annual Review of Condensed Matter Physics* 2(1): 375-399.
- Goo, E. , Majerczyk, C.D. , An, J.H. , Chandler, J.R. , Seo, Y.-S. , Ham, H. , ... Hwang, I. 2012. Bacterial quorum sensing, cooperativity, and anticipation of stationary-phase stress. *Proceedings of the National Academy of Sciences* 109(48): 19775-19780..
- Grover, D. , Chen, J.-Y. , Xie, J. , Li, J. , Changeux, J.-P. and Greenspan, R.J. 2022. Differential mechanisms underlie trace and delay conditioning in *Drosophila*. *Nature* 603(7900): 302-308.
- Hellingwerf, K.J. 2005. Bacterial observations: a rudimentary form of intelligence? *Trends in Microbiology* 13(4): 152-158.
- Hoffmeyer, J. 2002. The central dogma: A joke that became real. *Semiotica* 2002(138): 1-13.
- Igamberdiev, A.U. and Shklovskiy-Kordi, N.E. 2017. The quantum basis of spatiotemporality in perception and consciousness. *Progress in Biophysics and Molecular Biology* 130: 15-25.
- Jablonka, E. and Lamb, M.J. 1999. *Epigenetic Inheritance and Evolution: The Lamarckian Dimension*. Oxford, UK: Oxford University Press.
- Jablonka, Eva and Lamb, M.J. 2008. *The Epigenome In Evolution: Beyond The Modern Synthesis*. *Vosgis Herald* 12.
- Koonin, E.V. 2009. Darwinian evolution in the light of genom cs. *Nucleic Acids Research* 37(4): 1011-1034.
- Lamm, E. 2014. The genome as a developmental organ. *The Journal of Physiology* 592(11): 2283-2293.
- Lewontin, R.C. 1970. The Units of Selection. *Annual Review of Ecology and Systematics* 1(1): 1-18.
- Miller, W.B. 2013. *The Microcosm Within: Evolution and Extinction in the Hologenome*. Boca Raton, Florida, United States: Universal Publishers.
- Miller, W.B. 2016. *Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow*. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. and Torday, J.S. 2018. The Origins of Biological Deception: Ambiguous Information and Human Behavior. *Minding Nature* 11(3).
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological Evolution as Defense of "Self". *Progress in Biophysics and Molecular Biology* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology* 150: 112-139.
- Noble, D. , Jablonka, E. , Joyner, M.J. , Muller, G.B. and Omholt, S.W. 2014. Evolution evolves: physiology returns to centre stage. *The Journal of Physiology* 592(11): 2237-2244.
- Oyama, S. 2000. *The Ontogeny of Information: Developmental Systems and Evolution*. Durham, North Carolina: Duke University Press.
- Pigliucci, M. 2007. Do We Need An Extended Evolutionary Synthesis? *Evolution* 61(12): 2743-2749.
- Price, M.E. 2017. Entropy and Selection: Life as an Adaptation for Universe Replication. *Complexity* 2017: 1-4.
- Reber, A.S. 2019. *The First Minds: Caterpillars, Karyotes, and Consciousness (Illustrate)*. New York City, NY, USA: Oxford University Press.
- Ryan, F. 2009. *Viroolution*, New York, NY, USA: HarperCollins Publishers.
- Shapiro, J.A. 2009. Revisiting the Central Dogma in the 21st Century. *Annals of the New York Academy of Sciences* 1178(1): 6-28.
- Shapiro, J.A. 2011. *Evolution: A View from the 21st Century*. Upper Saddle River, NJ: FT Press.
- Shapiro, J. 2017. Living Organisms Author Their Read-Write Genomes in Evolution. *Biology* 6(4): 42.
- Stencel, A. and Crespi, B. 2013. What is a genome? *Molecular Ecology* 22(13): 3437-3443.

- Tagkopoulos, I. , Liu, Y.-C. and Tavazoie, S. 2008. Predictive Behavior Within Microbial Genetic Networks. *Science* 320(5881): 1313-1317.
- Tauber, A.I. 2000. Moving beyond the immune self? *Seminars in Immunology* 12(3): 241-248.
- Torday, J.S. 2015. A Central Theory of Biology. *Medical Hypotheses* 85(1): 49-57.
- Torday, J. and Miller, W. 2016. The Unicellular State as a Point Source in a Quantum Biological System. *Biology* 5(2): 25.
- Torday, J. and Miller, W. 2020. *Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology*. Cham, Switzerland: Springer.
- Torday, J.S. and Rehan, V.K. 2012. *Evolutionary Biology, Cell-Cell Communication and Complex Disease*. Hoboken, New Jersey: Wiley-Blackwell.
- Uller, T. , Moczek, A.P. , Watson, R.A. , Brakefield, P.M. and Laland, K.N. 2018. Developmental Bias and Evolution: A Regulatory Network Perspective. *Genetics* 209(4): 949-966.
- Walker, S.I. and Davies, P.C.W. 2013. The algorithmic origins of life. *Journal of The Royal Society Interface* 10(79): 20120869.
- Walker, S.I. and Davies, P.C.W. 2016. The “Hard Problem” of Life. *ArXiv Preprint ArXiv* :1606.07184.
- Walker, S.I. , Kim, H. and Davies, P.C.W. 2016. The informational architecture of the cell. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374(2063): 20150057.
- Walsh, D.M. 2014. The negotiated organism: inheritance, development, and the method of difference. *Biological Journal of the Linnean Society* 112(2): 295-305.
- Wang, Z. , Goyal, A. , Dubinkina, V. , George, A.B. , Wang, T. , Fridman, Y. and Maslov, S. 2021. Complementary resource preferences spontaneously emerge in diauxic microbial communities. *Nature Communications* 12(1): 6661.
- Witzany, G. 2010. Biocommunication and natural genome editing. *World Journal of Biological Chemistry* 1(11): 348.
- Witzany, G. (ed.). 2009. *Natural Genetic Engineering and Natural Genome Editing*. Hoboken, New Jersey: Wiley-Blackwell.
- Xavier, J.B. 2011. Social interaction in synthetic and natural microbial communities. *Molecular Systems Biology* 7(1): 483.

## Conclusion—The Intelligent Measuring Cell

- Auboeuf, D. 2021. The Physics—Biology continuum challenges darwinism: Evolution is directed by the homeostasis-dependent bidirectional relation between genome and phenotype. *Progress in Biophysics and Molecular Biology* 167: 121-139.
- Baverstock, K. 2021. The gene: An appraisal. *Progress in Biophysics and Molecular Biology* 164: 46-62.
- Bongard, J. and Levin, M. 2021. Living Things Are Not (20th Century) Machines: Updating Mechanism Metaphors in Light of the Modern Science of Machine Behavior. *Frontiers in Ecology and Evolution*, 650726.
- Brown, O.R. and Hullender, D.A. 2022. Neo-Darwinism must Mutate to survive. *Progress in Biophysics and Molecular Biology* 172: 24-38.
- Corning, P.A. 2020. Beyond the modern synthesis: A framework for a more inclusive biological synthesis. *Progress in Biophysics and Molecular Biology* 153: 5-12.
- Crkvenjakov, R. and Heng, H.H. 2022. Further illusions: On key evolutionary mechanisms that could never fit with Modern Synthesis. *Progress in Biophysics and Molecular Biology* 169-170: 3-11.
- Goldenfeld, N. and Woese, C. 2011. Life is Physics: Evolution as a Collective Phenomenon Far From Equilibrium. *Annual Review of Condensed Matter Physics* 2(1): 375-399.
- Marijuán, P.C. and Navarro, J. 2021. From Molecular Recognition to the “Vehicles” of Evolutionary Complexity: An Informational Approach. *International Journal of Molecular Sciences* 22(21): 11965.
- Marijuán, P.C. and Navarro, J. 2022. The biological information flow: From cell theory to a new evolutionary synthesis. *Biosystems* 213: 104631.

- Mayr, E. 1970. Populations, species, and evolution; an abridgment of Animal species and evolution. Cambridge, Massachusetts: Harvard University Press.
- Miller, W.B. 2016. Cognition, Information Fields and Hologenomic Entanglement: Evolution in Light and Shadow. *Biology* 5(2): 21.
- Miller, W.B. 2018. Biological information systems: Evolution as cognition-based information management. *Progress in Biophysics and Molecular Biology* 134: 1-26.
- Miller, W.B. , Baluška, F. and Torday, J.S. 2020a. Cellular Senomic Measurements in Cognition-Based Evolution. *Progress in Biophysics and Molecular Biology* 156: 20-33.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2019. Biological evolution as defense of "self". *Progress in Biophysics and Molecular Biology* 142: 54-74.
- Miller, W.B. , Torday, J.S. and Baluška, F. 2020b. The N-space Episenome unifies cellular information space-time within cognition-based evolution. *Progress in Biophysics and Molecular Biology*: 112-139.
- Neal, S. , McCulloch, K.J. , Napoli, F.R. , Daly, C.M. , Coleman, J.H. and Koenig, K.M. 2022. Co-option of the limb patterning program in cephalopod eye development. *BMC Biology* 20(1): 1.
- Noble, D. 2012. A theory of biological relativity: no privileged level of causation. *Interface Focus*(1): 55-64.
- Noble, D. 2021. The Illusions of the Modern Synthesis. *Biosemiotics* 14(1): 5-24.
- Torday, J. 2016. The Cell as the First Niche Construction. *Biology* 5(2): 19.
- Torday, J.S. and Baluška, F. 2019. Why control an experiment? *EMBO Reports* 20(10).
- Torday, J. and Miller, W. 2020. Cellular-Molecular Mechanisms in Epigenetic Evolutionary Biology. Cham, Switzerland: Springer.
- Woese, C.R. 2002. On the evolution of cells. *Proceedings of the National Academy of Sciences*(13): 8742-8747.