[5]Peter J. Bussey, "How Might God Have Guided Evolution? Scientific and Theological Viewpoints," *Perspectives on Science and Christian Faith* 73, no. 2 (2021): 91–99.
[6]John A. Wheeler, "Information, Physics, Quantum: The Search for Links," in *Proceedings III International Symposium on Foundations of Quantum Mechanics* (Tokyo: 1989), 354–68, https://philpapers.org/archive/WHEIPQ.pdf; and John Archibald Wheeler, *Information, Physics, Quantum: The Search for Links*—PhilPapers [Index].
[7]Moorad Alexanian, "Theistic Science: The Metaphysics of Science," *Perspectives on Science and Christian Faith* 59, no. 1 (2007): 85–86.

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Failure to Engage the Problem of Life's Origin

The discussion of "simplicity" versus "complexity" in abiogenesis seems to me to be the wrong question, and fails to engage the problem of life's origin in a specific way (Emily Boring, J. B. Stump, and Stephen Freeland, "Rethinking Abiogenesis: Part I, Continuity of Life through Time," *PSCF* 72, no. 1 [2020]: 25–36; and Emily Boring, Randy Isaac, and Stephen Freeland, "Rethinking Abiogenesis: Part II, Life as a Simplification of the Nonliving Universe," *PSCF* 73, no. 2 [2021]: 100–113). For one thing, the two terms are ambiguous, and were not defined sufficiently to allow a definite conclusion.

More importantly, the article glossed over the unique feature that makes life possible, namely, its ability to reproduce something after its kind. To accomplish this (in anything less trivial than crystals) required the emergence of a novel level of being, that is, a genetic code that is "gratuitous," decoupled from chemistry. The operon model with allosteric enzymes that was discovered by Monod, Jacob, and Lwoff (Nobel Prize 1965) is, after DNA, the "second secret of life." All of life exhibits this feature, and as such it perhaps should be included in the definition of life.

Freeland's persistent emphasis on continuity in abiogenesis ignores such decoupling and discontinuous system-level features of life. I wonder why, since it is widely emphasized in the classic literature on emergence, such as in Michael Polanyi's article on "Life's Irreducible Structure" (*Science* 160, no. 3834 [1968]: 1308–1312) and Philip Anderson's essay "More Is Different" (*Science* 177, no. 4047 [1972]: 393–96). I too wrote about this decoupling feature in an article on its application to information technology. The design of the internet, for instance, includes the idea of an information "packet" that contains external routing codes and an internal message. The content of the message is irrelevant—decoupled or "gratuitous" with respect to the routing of the packet (Paul T. Arveson, "Gratuity in Nature and Technology," *Journal of the Washington Academy of Sciences* 85, no. 4 [1998]: 281–89).

The discovery of novel ontological levels in nature has, I believe, useful applications for ASA members, as a refutation of reductionism and as an awareness of category distinctions that we commonly encounter in science and faith discussions.

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"Rethinking Abiogenesis Part II" Authors Respond

We thank Arveson for raising some key points of discussion. While we do not formally define "simplicity" or "complexity," we do identify specific features of life that present lower diversity and less randomness than the universe at large. Our intent is not to declare biological complexity wrongheaded, but rather to suggest that other views are possible and worthy of deeper consideration. However, Arveson's main focus is the underlying point of both our papers (Emily Boring, J. B. Stump, and Stephen Freeland, "Rethinking Abiogenesis: Part I, Continuity of Life through Time," *PSCF* 72, no. 1 [2020]: 25–35; and Emily Boring, Randy Isaac, and Stephen Freeland, "Rethinking Abiogenesis: Part II, Life as a Simplification of the Nonliving Universe," *PSCF* 73, no. 2 [2021]: 100–113), which he accurately summarizes as the following challenge: Does any clear, objectively defined state of (bio)chemistry distinguish nonliving chemistry from living biology?

We agree that life may be distinguished clearly from nonlife from the perspective with which we perceive the world today. In particular, the Central Dogma of Molecular Biology[1] reflects five mid-twentieth-century Nobel prizes which collectively define the material (molecular) basis for all known life:[2] nucleic acid genes specify protein catalysts which synthesize nucleic acid genes. Collectively, these components establish what Arveson calls "*the unique feature that makes life possible, namely, its ability to reproduce something after its kind*." Indeed, Arveson refers to a sixth Nobel prize from the same time period—Monod and colleagues' discovery of operons, regulatory networks among genes of related function,[3] a construct within the central dogma—as being "*after DNA, the 'second secret of life'*" (alluding to Crick's declaration that the structure of DNA is, by itself, the secret of life).[4] These mighty figures of science were focused on the profound insight that life as we know it can be defined in terms of a simple, universal basis. With this focus, a view of life forms which resonates with themes of system-level thinking and emergent properties, characterizing the philosophical essays of Polanyi and Anderson. It is no coincidence to us that their essays arrived as the central dogma was becoming established.

Where we respectfully diverge from these ideas is whether, decades later, the central dogma can be reasonably considered a minimum threshold for life, and thus an objective definition of where life begins. We suggest that both the material basis of this definition (the molecular components of the central dogma) and the decoupled, gratuitous features they produce are clearly outcomes of biological evolution, not preconditions for biological evolution.

To make this assertion, our articles summarize some of the subsequent research that informs prior states from which the central dogma evolved. We point to examples of such work (including a seventh Nobel prize that eroded the functional roles assigned to different biopolymers within the central dogma[5]) and examples of chemical evolution which, we suggest, may collectively account for the evolution of the central dogma in increments (including the decoupled gratuity we now see). For example, a leading theory for the origin of the genetic code builds exactly from the principle that today's decoupled system evolved from direct chemical affinities between amino acids and RNA sequences.[6] Together, such findings cause us to question whether any objective demarcation separates evolving, living systems from evolving chemical systems. Our conclusion is that a perspective of life's continuity with the nonliving universe may provide a more helpful view of abiogenesis for both science and theology.

Where we must rightfully concede is the diminishing scientific detail that currently describes biologies increasingly far removed from (prior to) the central dogma. A world without DNA is well supported at this point, and likewise, a world of fewer than twenty genetically encoded amino acids. Ribozymes (RNA enzymes) are an empirical fact, although an RNA world without proteins remains actively researched and debated as a stage in evolutionary history. A world of pre-RNA fragments interacting within pre-lipid membranes may be cautiously inferred but, even then, a significant gap, populated somewhat sparsely by theory and mathematical models,[7] separates this "proto-living system" from such well-described, simple, and intuitively nonliving self-replicators as crystals and fire. Perhaps then our central idea is helpfully summarized as the suggestion that this gap is where we anticipate the most interesting, near-term progress as an emerging challenge to an established, classical view. So long as it is understood as such, then we are proud to make our suggestion so within *PSCF*. ✝

Notes

[1]Francis H. C. Crick, "Central Dogma of Molecular Biology," *Nature* 227 (1970): 561–63.

[2]George Wells Beadle, Edward Lawrie Tatum, and Joshua Lederberg, The Nobel Prize in Physiology or Medicine 1958, https://www.nobelprize.org/prizes/medicine/1958/summary/; Francis Harry Compton Crick, James Dewey Watson, and Maurice Hugh Frederick Wilkens, The Nobel Prize in Physiology or Medicine 1962, https://www.nobelprize.org/prizes/medicine/1962/summary/; Robert W. Holley, Har Gobind Khorana, and Marshall W. Nirenberg, The Nobel Prize in Physiology or Medicine 1968, https://www.nobelprize.org/prizes/medicine/1968/summary/; Max Delbrück, Alfred D. Hershey, and Salvador E. Luria, The Nobel Prize in Physiology or Medicine 1969, https://www.nobelprize.org/prizes/medicine/1969/summary/; Christian B. Anfinsen, Stanford Moore, and William H. Stein, The Nobel Prize in Chemistry 1972, https://www.nobelprize.org/prizes/chemistry/1972/summary/.

[3]François Jacob, André Lwoff, and Jacques Monod, The Nobel Prize in Physiology or Medicine 1965, https://www.nobelprize.org/prizes/medicine/1965/summary/.

[4]Howard Markel, "The Day Scientists Discovered the 'Secret of Life,'" PBS NewsHour (February 28, 2013), https://www.pbs.org/newshour/health/the-pub-where-the-secret-of-life-was-first-announced.

[5]Sidney Altman and Thomas R. Cech, The Nobel Prize in Chemistry 1989, https://www.nobelprize.org/prizes/chemistry/1989/summary/.

[6]Michael Yarus, "Evolution of the Standard Genetic Code," *Journal of Molecular Evolution* 89, no. 1-2 (2021): 19–44.

[7]Zhen Peng et al., "An Ecological Framework for the Analysis of Prebiotic Chemical Reaction Networks," *Journal of Theoretical Biology* 507 (2020): 110451.

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