fortune Journals

Review Article

JOURNAL OF BIOINFORMATICS AND SYSTEMS BIOLOGY

ISSN: 2688-5107

Defining "Life"

David Lynn Abel

Abstract

At what point does a theoretical protocell/protobiont come to life [1-13]? A cell becomes alive by definition when it is observed to be actively *Processing Efficacious Executable Choice-Commanded Causation and Control (PEECCCC) [14-22]* . No inanimate entity has ever been observed to manifest this trait/capability. Every universally agreed-upon free-living cell without exception manifests this trait/capability. Viruses and viroids correspond best to non-living thumb drives. Prions are nothing more than misfolded proteins. Suspended animation is a very special case of *discontinued active ongoing living process*. This means that entities in suspended animation have the potential to come to life, but are not *currently* living. The dichotomy between life and non-life is not a gray-scale transition. This definition provides a digital, crystal-clear, yes-or-no absolute. A cell is either actively exercising this unique *functional* process, or it is not. *PEECCCC* is a fully testable and falsifiable working definition of "life." It is all-encompassing of the entire array of living organisms, whether single-celled; multi-celled; sterile/nonreproducing (e.g., the "mule problem"); and currently evolving or not evolving. *PEECCCC* is applicable to Monera, Protista and on up to the remaining three Kingdoms of life. Interestingly enough, this definition is also fully applicable to NASA and astro/exobiology pursuits. "Biosignatures" include the functional processing devices designed and engineered by subcellular life to process its own undeniable cybernetic programming. PEECCCC is alone what produces life's formal computational halting and its programming of extraordinary degrees of "end user freedom."

Keywords: Life vs. Non-life; Animacy vs. Inanimacy; The Definition of Life; Life Origin; Abiogenesis; Computational Biology; The Universal Determinism Dichotomy (UDD); The Formalism > Physicality (F > P) Principle; The Physicodynamic Incompleteness Theorem (PIT); The Genetic Selection (GS) Principle; Protocellular Metabolomics; ProtoBioCybernetics; ProtoBioSemiotics.

Background

For centuries scientists and philosophers have sought to define "Life." Most prominent in the 20th century was probably Schrödinger's 1944 book "What is life?" He attempted to reduce life to nothing more than physicodynamics. Almost all abiogenesis and life-defining (describing) papers since have pursued the same goal. Since Watson and Crick's paper in 1953, increasingly the naturalistic science of biology has found itself haunted by a nasty impasse: Life simply cannot be crammed into naturalistic science's purely metaphysical naturalistic presupposition. Life manifests peculiar biosignatures of extraordinary function and steering controls that cannot be

Affiliation:

ProtoBioCybernetics/Protocellular Metabolomics, The Gene Emergence Project, The Origin of Life Science Foundation, Inc USA.

***Corresponding author:**
David Lynn Abel, ProtoBioCybernetics/ Protocellular Metabolomics, The Gene Emergence Project, The Origin of Life Science Foundation, Inc USA.

Citation: David Lynn Abel. Defining "Life". Journal of Bioinformatics and Systems Biology. 9 (2026): 18-27.

Received: January 25, 2026
Accepted: January 30, 2026
Published: February 07, 2026

Dr.David Lynn Abel., J Bioinform Syst Biol
2026 DOI:10.26502/jbsb.5107109

logically produced by Chance and Necessity. In addition, zero empirical evidence exists of the blindly-believed "self-organization" and "emergence" of sophisticated function from physicodynamics alone.

"Being alive" manifests undeniable formal effects that can only have formal causes. Even in the study of inanimate physicality—physics—nonphysical, abstract, conceptual, formal mathematics governs practically every law and force. Are we sure that formalistic causes of physical interactions are as "unreasonable" as Einstein [23], Wigner [24], Hamming [25] and Endres [26] surmised? Could it be that Einstein's edict of minimizing metaphysics in order to protect science was violated by the inclusion of metaphysical "physicalism" into the very definition of science?

The origin of "Function"

Inanimate physicodynamics has never been observed to generate refined *function* of any kind [27-32]. Physicodynamics is blind to function. Mass/energy interactions could care less whether anything "works." Work as defined by physics has absolutely nothing to do with "usefulness." The wind blowing a tumble weed up a hill is "work" in physics. Physics is not interested in ever asking the question, "So What?" Questions of "utility" are irrelevant in naturalistic physics. Physicodynamics doesn't pursue the goal of function or "efficaciousness." Physics and chemistry know nothing of pragmatism.

Scores of sophisticated newly recognized biofunctions are being elucidated monthly in the literature. All of these require programming with choice-based commands at bona fide decision nodes for life to exist and to stay alive. Undeniable "choices" continue with genomic and epigenomic algorithmic optimizations used to adapt to environmental challenges [33]. Any proposed working definition of "life" must explain how these formal controls were first chosen and executed in any protobiont [14-16]. Our purely metaphysical imperative that "Choice is too teleological" denies ontological fact. Neither sophisticated function nor life can be explained without choice commands and controls. If life is characterized by anything, it is actual choices made in pursuit of biofunction at *bona fide* "decision nodes." These physicodynamically-inert choices are made according to rules, not laws. They are the key to the programmed computation [17] characteristic of all known lifeforms.

So, where did function come from? Abiogenists' answer is "self-organization" and "emergence." Both terms and concepts can be found in probably 90% of all well-indexed peer-reviewed abiogenesis papers. Yet "self-organization" and "emergence" of substantial formal function are totally without empirical support. "Self-organization" is a self-contradictory nonsense concept and term that has no place in science. Something would have to already exist in order to formally organize anything. But if it already exists, how could it possibly organize itself into existence? How could such an absurdity possibly be so widely accepted in scientific literature?

Blind belief in the spontaneous "emergence" of highly refined formal function is no better. In the history of human observation, sophisticated function has *never* been observed to just "self-organize" or to just spontaneously "emerge" from undirected raw physicodynamics. No one has ever observed a simple piece of wire emerge out of iron ore in the ground. Why not? The answer is that the generation of non-trivial function requires a certain causative factor not present in raw physicodynamics: *Controls*, rather than mere constraints [34]. Controls are formal, not physicodynamic. Controls must be chosen. The notions of "self-organization" and "emergence" by nothing more than raw physicodynamics are both nothing less than absurd! They are nonsensical pipe dreams necessitated by the altogether faulty purely metaphysical presupposition that "Mass/Energy interactions are sufficient to explain everything." Einstein warned us about the need to minimize metaphysics. He also pondered "The unreasonable effectiveness of formal mathematics in the physical sciences" [23, 35]. The only thing that made mathematical governance of physicality "unreasonable" was the purely philosophic pre-assumption of physicalism. Why would any responsible scientist believe that homeostatic metabolism could just spontaneously emerge from physicodynamics alone in any amount of time? The only answer is that their philosophic perspective is locked into a purely physicalistic metaphysic. They have no choice but to reduce reality to Chance and Necessity. Nothing else is allowed into naturalistic science by a physicalistic presupposition illegitimately incorporated into the very definition of science as its starting axiom. Mathematics is not physical. Language is not physical. Logic theory is not physical. The scientific method itself is not physical.

We are not giving due diligence to the Formalism > Physicality (F > P) Principle [15-19, 33, 36-39].

"The F > P Principle states that 'Formalism not only describes, but preceded, prescribed, organized, and continues to govern and predict Physicality." The F > P Principle is an axiom that defines the ontological primacy of formalism in a presumed objective reality that transcends both human epistemologies, our sensations of physicality, and physicality itself. The F > P Principle works hand in hand with the Law of Physicodynamic Incompleteness, which states that physicochemical interactions are inadequate to explain the mathematical and formal nature of physical law relationships. Physicodynamics cannot generate formal processes and procedures leading to nontrivial function. Chance, necessity and mere constraints cannot steer, program or optimize algorithmic/computational success to provide desired nontrivial utility. As a major corollary, physicodynamics cannot explain or generate life. Life is invariably cybernetic.

Dr.David Lynn Abel., J Bioinform Syst Biol
2026 DOI:10.26502/jbsb.5107109

The F > P Principle denies the notion of unity of Prescriptive Information (PI) with mass/energy. The F > P Principle distinguishes instantiation of formal choices into physicality from physicality itself. The arbitrary setting of configurable switches and the selection of symbols in any Material Symbol System (MSS) is physicodynamically inert or indeterminate—decoupled, that is, from physicochemical determinism." [37]

Thomas Kuhn warned us about paradigm ruts [40]. Yet, the first thing any naturalistic scientist is going to want to do with the origin of "function" is to immediately disallow any discussion of "Choice." "It's too teleological." The problem is that non-trivial refined function is *logically* impossible to achieve without making purposeful choices. In addition, sophisticated functions empirically have never been observed to arise without Choice Causation. The only need to disallow "choice" from the generation of non-trivial refined function arises out of a purely *metaphysical* imperative, not because of any logical or empirical shortcoming of the Universal Determinism Dichotomy (UDD) [41]. The UDD states that all practical macroscopic effects arise from one of two categories of causation: either Physicodynamic Determinism, or Choice Determinism.

"Chance and Necessity" (mass/energy interactions according to laws and forces) comprise the Physicodynamic Determinism category of causation. Chance, however, is generally not regarded as a true cause of any effect. It is merely a probabilistic description of what might happen as a result of complex, poorly understood, interactive Necessity (physical law-like determinism). The classic cause-and-effect chains involving initial conditions, the effects of force fields and the laws of motion are aspects of Physicodynamic Determinism (PD). Although the physical world seems ruled by physical cause-and-effect determinism, a seemingly independent phenomenon, contingency, is also frequently observed. Contingency means that events can occur in multiple ways despite the monotonous/redundant constraints of physical law, constant initial condition constraints, and set probability bounds. But there are two kinds of Contingency: 1) Chance Contingency and 2) Choice Contingency. Of special interest is the reality of physical effects caused by formal Choice Causation originating from the far side of The Cybernetic Cut across the one-way narrow Configurable Switch (CS) Bridge into the near physicodynamic side of reality."[41]

The Cybernetic Cut [42-46] is the great ravine that divides the abstract, conceptual non-physical formal aspects of reality from physicodynamic reality. Configurable switches are physical devices that are designed and engineered to record abstract, non-physical, formal choices into physicality. Another means of traversing the great ravine known as The Cybernetic Cut across the narrow, one-way CS Bridge [42, 44] is the active selection of physical symbol vehicles used in Material Symbol Systems (such as when playing the game of Scrabble). Whether our philosophical worldview likes it or not, there will be no trashing of the essential element of Choice Determinism from generating formal non-trivial "function." We might pause for a moment here to ask why we are devoting so much discussion of "function" to a paper that is supposed to be actually defining life for the first time in scientific literature. The answer will become plain as we realize how integral "function" is to life's definition.

Why is it that the only known source of engineering is life? What is it about life that enables life to produce the unique biosignature of engineering science? The answer is that life itself is engineered at the subcellular level. This is proven by the fact that all known life is programmed with syntactical semantic and efficacious choice commands represented in formal symbol systems using physical symbol vehicles. Physical symbol vehicles such as nucleosides must be purposefully chosen and polymerized into linguistic-like syntax. Symbol systems are based on rules, not laws. Any formal system requires choices to formally organize and orchestrate. These choice commands at the subcellular level are cybernetically processed by nano-computers and very sophisticated molecular machines. In addition, "physicodynamically-inert" configurable switches are formally set by the choice of epigenetic markers. These *choices* of whether to methylate certain loci on DNA determine whether genes are turned "On" or "Off." "Yes" or "No" is chosen as to whether the logic gate is open or closed. "Active or Inactive" is actively selected. Epigenetic switches provide opportunity for formally chosen logic-gate settings to be established into physical reality. Life depends upon chosen epigenetic configurable switch-settings and alternatively selected lncRNA splicings. The latter allow scores of different proteins and other RNAs to be produced by the same gene. The cell actively chooses which alternate splicing it wants and needs.

Neither life's programming nor the subcellular "devices" that process that programming have ever been observed to just "emerge" or "self-organize" from raw mass/energy interactions [47]. So how did they arise in a prebiotic environment? What caused the effects of programming and the formal choice-mediated circuit integration of such sophisticated configurable switches? What crafted Material Symbol Systems (MSSs) [48, 49] in an inanimate environment? MSSs are the other means of choices traversing the CS Bridge into physicality besides configurable switch-settings. They are no easier to explain naturalistically. The generation of sophisticated function is unique to life [50-53]. This is true not only of life's biosignatures, but of subcellular life itself. Life is uniquely marked by ongoing processing of highly refined halting computations [14-17]. How does life accomplish this? How did life's programming, cybernetic processing and halting computations get started in an inanimate prebiotic environment?

As previously mentioned, mass/energy phenomena

Dr.David Lynn Abel., J Bioinform Syst Biol
2026 DOI:10.26502/jbsb.5107109

are blind to "usefulness." The celebrated irreversible nonequilibrium thermodynamics lacks steering and directionality toward any form of functional success [38, 52]. Laws and constraints have no perception of or interest in achieving utility. Non-trivial function doesn't just happen. The effect of "refined function" must have a cause.

Life Is Controlled by Efficacious Executable Choice Commands

The process of living requires Choice Determinism to steer and direct coming to life and staying alive. Life's programming and computations are formalisms, not physicodynamic Necessity. Everything about subcellular and cellular life hinges upon Controls. Controls must be uniquely commanded at bona fide "decision nodes." Active selections must be made, not just the passive, secondary, after-the-fact phenotypic selections of evolution. Orchestrational orders must be issued and followed if efficacious sophisticated function is expected. Virtually all biological peer-reviewed literature affirms this, although usually without our realizing this fact's full significance. We are blinded by our starting purely presuppositional axiom that we defined into science without thinking things through. Now, the entire field of naturalistic biological science has encountered the exact same impasse encountered with the science of Engineering. The problem is, we cannot excommunicate the science of Biology from natural science the way we did so conveniently with Engineering Science. Our dilemma is the fact that Life is steered, directed and controlled by choice commands, not by blind physicodynamic laws and constraints.

Is there any geneticist or epigeneticist in the world who can explain biological controls without choice commands that are necessarily issued at bona fide "decision nodes?" The bifurcation points measured by what this author calls "Shannon's Uncertainty Theory" do not measure efficacious active selections at decision nodes. The Shannon equation measures statistical possibilities in phase spaces, not the formal accomplishments achieved through specific purposeful choices. Yet the latter is the key to "life." Shannon himself was appalled by calling his work a measure of "information" [54]. Shannon knew better than anyone, with great frustration, that his work measured only uncertainty rather than efficacious choices. But it is choices at bona fide "decision nodes," and choices alone, that bring physicality to life. These choices are issued in the form of pre-programmed executable commands, and those commands within cells include the choice commands needed to design and engineer the nano-computers and stunning molecular machine devices needed to actually execute those commands. Evolution must explain how both suddenly appeared within the same protocell at the same time and place. The programming of life is worthless without programmed and engineered devices needed to process that programming.

No programmer ever wrote a program with Chance Contingency or Law. We know full well the difference between Chance and Choice Contingency, and that Choice Determinism is real. The science of Engineering proves it. And we know that engineering is a unique biosignature of life, as NASA would call it. All known life is programmed and cybernetically processed [17]. What exactly is programming? A related question is, "When we say that epigenetics '*regulates*' whether genes are turned on or off, what do we mean?" "On" or "Off" is a *digital programming choice*. It's a logic gate operation. The methylation of a certain locus on DNA constitutes the setting of a digital configurable switch. That switch-setting records a purposeful active selection from among two physical options. The choice is made to either turn the gene on or off.

Operons and enhancers have to be chosen to produce needed proteins and lncRNAs [55-58]. Alternate splicings have to be chosen [59-63]. One means of rapid adaptation requires choice of the number of Tandem Repeats used in prescribed polymorphisms [33, 64-69]. Highly specific acetylation sites must be chosen in histones to determine needed chromatin coiling [70-77]. Decisions must be made as to when allosteric and orthosteric activators or inhibitors are to change enzyme or receptor conformations [78-82]. The use of telomer shortening and telomerase to control the timing of cellular death [83-85] requires choice. The list seems endless of the choices controlling biofunction.

We could go on with hundreds more examples of sophisticated biofunctions, all of which have to be chosen programmatically for life to exist and to stay alive. Choices continue with genomic and epigenomic algorithmic optimizations used to adapt to environmental challenges [33]. Any proposed working definition of "life" must include the fact of these formal controls [14-16]. All known lifeforms have metabolisms mediated by programmed formal *Controls.* Even the four-dimensional genomic programming is turned on and off by epigenetic choices [86-91]. Choice distinguishes controls from constraints [34]. Controls formally direct physicodynamic events toward integrated biofunction and successful computation [27-29, 31, 92].

These choice controls emanate from the far side of The Cybernetic Cut [42, 44, 46]. They traverse the narrow one-way Configurable Switch (CS) Bridge into the near physicodynamic side across the great ravine of The Cybernetic Cut. Purposeful choices are instantiated into configurable switch-settings. Although themselves physical, the setting of these switches is physicodynamically inert and altogether formal [45, 48, 93-95]. An alternate means of instantiation of purposeful choices into physicality is the active selection of physical symbol vehicles (tokens) used in Material Symbol Systems [48, 49]. The physical symbol vehicles and their syntax formally *represent* and *control* efficacious executable choice commands.

Dr.David Lynn Abel., J Bioinform Syst Biol
2026 DOI:10.26502/jbsb.5107109

The choice of each nucleoside out of four options begins the generation of the Prescriptive Information (PI) that makes life possible.

What is Prescriptive Information (PI) [50, 51, 96]?

"Semantic (meaningful) information has two subsets: Descriptive and Prescriptive. Prescriptive Information (PI) is not just descriptive. PI instructs *and* programs. When processed, PI is used to produce nontrivial formal functions. Merely describing a computer chip does not prescribe or produce that chip's function. Thus, mere description needs to be dichotomized from the chip's actual prescription and production of function. Computationally halting cybernetic programs and linguistic orders to do something that empirically proves to be successful are examples of Prescriptive Information. *"Prescriptive Information (PI) either tells us what choices to make, or it is a recordation of efficacious choices already made."* [96]

Prescriptive Information (PI) is what is instantiated into physicality through the active on-going Processing of Efficacious Executable Choice-Commanded Causation and Control (PEECCCC). Without Prescriptive Information, no life would exist. PI is what makes programmed computation possible. Raw physicodynamics is simply not up to the task of needed orchestration and causative formal effects. Since "organization" is so often mis-defined solely in terms of mere physical "order," "orchestration" is a more precise and accurate term to describe how life's circuits get formally integrated into holistic homeostatic metabolism far from equilibrium. But the proper definition of "organization" is also formal and choice-based. No choices are required for Prigogine's self-ordering "dissipative structures" [97-101]. Choices are always required to achieve formal "organization." Life is organized, not physicodynamically self-ordered [29, 32].

The models of life-origin science are very helpful in reducing the essence of life to a more manageable investigation. But the Achillies heel of all existing naturalistic abiogenic models is their failure to explain the derivation of primordial prescription of biofunction and control. Our focus on mutations must be preceded by our first answering the question, "Mutations of *WHAT?*" [15] What exactly is it that mutates? All known life is programmed and cybernetically processed [16, 17]. What caused such successful genomic programming prior to its alteration with mutations? Typographical errors do not write PhD theses. Mutations do not write genomes [18, 19, 21, 22, 39].

The Elusive, Long-Sought-After Definition of "Life"

"Processing" is the first essential element in this new long-awaited definition of life. For any entity to be considered alive, it must be *actively processing* homeostatic metabolism far from equilibrium [102, 103]. This is simultaneously both the beginning and the ultimate in functionality. Functionality is produced by active formal processing. Algorithms are stepwise choice-based procedures. Any definition of life must define the gerund phrase, "being alive" in an active ongoing procedural sense through time. Life is a *Sustained* Functional System (SFS) [14, 16, 17, 19, 21, 38, 102] employing ongoing, active algorithmic processing, not an event or momentary state.

The second crucial element in this definition of "being alive" is that the process is "Efficacious." It successfully does whatever it is supposed to do. It completes its task of performing some desired or useful function. It's computation "halts" [17]. Life achieves being alive, and maintains being alive as an undeniable goal. Even apoptosis, the highly-regulated deliberate process of cells killing themselves, is efficacious in protecting the life of the overall organism [104-110].

The next essential aspect of this definition is best addressed jointly as "Executable Commands." Life doesn't just provide recipes and instructions for how to do something useful. Life's genomic and epigenomic commands actually *do* what needs to be done [43, 45, 111, 112]. The important point at the moment is that life's commands are *doable*. Each command is precisely defined and freely executable despite often being a part of incredibly conceptually complex integrated circuits of operations. The executable commands are digital, yet their programming is so sophisticated as to often produce analogue-like effects. Responses are precise and reliable, given the formal system and reliable devices put into place to accompany the programming.

An aspect of these executable commands is that "obedience" to each pre-recorded command has been made reliable through simultaneous equipment/device design and engineering. The necessary processing equipment appears at the same place and time with the cell as the Prescriptive Information (PI) [51] inherent in the commands. The commands include the "how to" of executable response by the devices. Successful computation is rightly expected. If halting were to fail, however, changes can be made in the instruction set to achieve success through algorithmic optimization at the genetic/genomic/epigenomic level. The Genetic Selection Principle [113, 114] emphasizes that evolutionary selection ultimately takes place at the genetic level, not the phenotypic level. Phenotypes are secondary, not primary. Failure to appreciate this fact is what caused the error of Lamarckism. The only thing that gave new life to Lamarckism was the discovery of epigenetic configurable switch-settings, alternate lncRNA splicings, and other prescribed polymorphisms. Purposeful changes in the number of Tandem Repeats in response to abrupt environmental challenges is a classic example. These changes are still genomic rather than phenotypic. Environmental challenges can induce the calling

Dr.David Lynn Abel., J Bioinform Syst Biol
2026 DOI:10.26502/jbsb.5107109

up into upper memory of various programming modules already in the genome. Such prescribed polymorphisms can also last several generations. Such algorithmic optimizations are regularly performed by the genome. They are not just spontaneous mutations [33].

The next essential term in this working definition is "Control." Life is controlled, not just constrained. Interactions are steered toward the goal of biofunctional success. Epigenetic *regulation* requires active selections from among real options. The Universal Determinism Dichotomy (UDD) defines this as Choice Determinism, not Physicodynamic Determinism [14-17, 33, 41]. Events are specifically directed toward pragmatic needs by choice. Life "desires" and chooses to be alive and to stay alive, whether this fact corresponds to our purely philosophic naturalistic presuppositions, or not.

We are not very comfortable talking about "controls" in naturalistic science. We prefer instead to convert all such discussion to talk only about constraints. What is the difference between controls and constraints? The answer was provided in great detail in a 2010 paper [34]:

"The terms constraints and controls should not be used interchangeably. Constraints refer to the cause-and-effect deterministic orderliness of nature, to local initial conditions, and to the stochastic combinatorial boundaries that limit possible outcomes. Bits, bifurcation points and nodes represent "choice opportunities", not choices. Controls require deliberate selection from among real options at those "nodes." Controls alone steer events toward formal pragmatic ends. Inanimacy is blind to and does not pursue utility. Constraints produce no formal integrative or organizational effects. Only the purposeful choice of constraints, not the constraints themselves, can generate bona fide controls. Configurable switch-settings allow the instantiation of formal choice contingency into physicality. While configurable switches are themselves physical, the setting of these switches to achieve formal function is physicodynamically indeterminate—decoupled from and incoherent with physicodynamic causation. The mental choice of tokens (physical symbol vehicles) in a material symbol system also instantiates nonphysical formal Prescriptive Information (PI) into physicality." [34]

So now that the difference between controls and constraints is clear, is either of these two unique to life? Constraints are universal to physicality. There is nothing unique about constraints. Constraints affect both life and non-life. But does inanimacy generate nontrivial formal controls? No. No such empirical evidence exists. Does life manifest true controls? Any scientist who doubts that life manifests *controls* should read any one of the hundreds of genomic, epigenomic, or molecular biology papers being published this month in scores of peer-reviewed, well-indexed journals. Everything about life involves controls. If we listed examples proving the point, this paper would quickly exceed a hundred pages. Read any one molecular biological paper coming out this month, and then try to argue that life is not controlled at the subcellular, cellular and multicellular levels. Even the "natural" science of biology now demands acknowledgement of life's on-going Processing of Efficacious Executable Choice-Commanded Causation and Control (PEECCCC) [14]. But note that this *full* proposed working definition of life includes the fact that these commands are *Choice* commands [94]. They originate from decisions at bona fide "decision nodes." The commands are chosen from among multiple real options. As in Shannon theory, the options can be binary, tertiary, quaternary, etc. But unlike Shannon theory, "uncertainty" and "possibility" at that node are replaced with absolute certainty by virtue of purposeful choice. What *was* a statistical epistemological measure suddenly becomes an acquired choice causation with a probability of 1.0 (assuming the processing scheme and devices are in proper working order, which themselves must be prescribed and processed). Efficaciousness and computational halting are empirically achieved through efficacious choice commands.

Objective biofunction was produced in Monera long before any humans existed to "know" anything about uncertainty or choice. The problem of abiogenesis is not an epistemological problem. It is an ontological problem. Life's causation was objective, not subjective. Human knowledge and understanding were not factors. We often make the mistake of trying to relegate objective reality to our own pathetic epistemology. When we include the word "choice" in our definition of "life," immediately our naturalistic hackles go up. "What do you mean, Choice?" This proposed working definition of life was already in a bit of metaphysical trouble the minute we started talking about "Commands" and "Controls." Naturalism wants to limit all discussion to Monod's "Chance and Necessity." "Commands" and "Controls" seem too anthropocentric. We only want to consider physicodynamic law, forces, waves, natural attractions/repulsions, and other aspects of Necessity. Nevertheless, the full proposed definition of life *must* include "Choice-Commanded Controls."

We tend to argue, "Why does 'choice' have to be included? The inclusion of 'choice' smacks of too much agency. Our explanation needs to be more teleonomic, and not so teleological." Why is this our perspective? The only reason is that our purely metaphysical presupposition that "Chance and Necessity are sufficient" demands it. Open-minded philosophers of science might ask, "Sez who?"

The problem is, the undeniable Controls of life require the equivalent of "Chosen Executable Commands." Not only do instructions have to be given. Direct orders have to be given. "Obedience" to those orders by the processing system is necessary. But we are not talking here about the "necessity" of law. *Guidance* is necessary. *Steering* is required. *Directives*

must be issued if non-trivial efficacious results (functionality) are to be an observed caused effect. Formal function has to be directed by choices for metabolism to be realized. Biochemical pathways have to lead somewhere useful. These pathways have to be formally integrated into holistic metabolism. Usefulness has to be pursued with purposeful choices. When it comes to non-trivial function, physicodynamics is utterly "dumb." "Order" is usually confused with "organization" in a physicalistic worldview. The two HAVE TO BE conflated given the presuppositional imperative that physicality is all there is. But mere physical order is not the formal organization we clearly observe in free-living organisms. Self-ordering occurs all the time in nature. Self-organization does not. Organization is choice-based and formal, not physical, although physicality can be formally organized by choices. Life alone produces the choices required for formal organization. Life itself is formally organized at the subcellular level on up. This presents still another "chicken and egg" dilemma for naturalistic life-origin science. The Universal Determinism Dichotomy (UDD) will always come into play [41]. Only Choice Determinism can cause the effect of efficacious choice-controlled commands and life's formal computations [36, 37, 43].

Conclusion

Anything "alive" is actively Processing Efficacious Executable Choice-Commanded Causation and Control (PEECCCC). If we cannot falsify this working definition of "life," we had better begin reconsidering the most fundamental metaphysical presupposition that we illegitimately defined into science, that "Physicalism is sufficient to explain the whole of reality." This paper invites the world's biological community to falsify or improve this long-awaited formal working definition of "being alive"—the active ongoing PEECCCC that alone produces life's formal halting computations.

References

1. Tsokolov SA, Why Is the Definition of Life So Elusive?. Epistemological Considerations 9 (2009).
2. Yan Y, et al. Nanoclay-Peptide Interfaces Mediate Prebiotic Chemical Evolution in the Origin of Life. Nano Lett 25 (2025): 15714–15722.
3. Tenuta S, et al. Bio-mediated CN cycling in serpentinites and the origin of life. Sci Rep 15 (2025): 22452.
4. Nemchinov LG. The origin and evolution of life as continuing expansion of viral hosts. Biosystems 257 (2025): 105609.
5. Maury CPJ. Origin of life: beta-sheet amyloid conformers as the primordial functional polymers on the early Earth and their role in the emergence of complex dynamic networks. FEBS Lett 599 (2025): 2693–2705.
6. Jin Y. On the Origin of Life on Earth: The Nanozymes Hypothesis, and More. Research (Wash D C) 8 (2025): 1025.
7. Gomez-Marquez J. The Origin of Life and Cellular Systems: A Continuum from Prebiotic Chemistry to Biodiversity. Life (Basel) 15 (2025): 11.
8. Golubev AG. Chemistry of the Joint Origin and Evolution of Life, Death, and Aging. Biochemistry (Mosc) 90 (2025): 1188–1213.
9. Eiby SHJ, Hassenkam T. Who Decides What Is Prebiotically Plausible? The Risks of Premature Constraints in Origin-of-Life Research. Life (Basel) 15 (2025): 11.
10. Edri R, et al. From Polymerization-Enabled Folding and Assembly to Chemical Evolution: Key Processes for Emergence of Functional Polymers in the Origin of Life. Astrobiology (2025).
11. Diukarev N, et al. The Origin of the Feedstock Molecules for Life on the Hadean Earth. Angew Chem Int Ed Engl 64 (2025): e202512374.
12. Brack A. Reflections on Keywords: Definition, Life and Origin. Life (Basel) 15 (2025): 9.
13. La D. Directionality theory and the origin of life. R Soc Open Sci 11 (2024): 230623.
14. Abel DL. The Life/Non-Life Dichotomy. J Bioinform Syst Biol 9 (2026): 1–17.
15. Abel DL. Mutations of WHAT? J Bioinform Syst Biol 8 (2025): 83–98.
16. Abel DL. The Common Denominator of All Known Lifeforms. J Bioinform Syst Biol 8 (2025): 29–35.
17. Abel DL. Life is Programmed Computation. J Bioinform Syst Biol 8 (2025): 1–16.
18. Abel DL. Physicodynamic Incompleteness Updated in 2025 from 2009. Scirus Sci-Topic Paper (2025).
19. Abel DL. What is Life? Arch Microbiol Immunol 8 (2024): 428–443.
20. Abel DL. Selection in molecular evolution. Stud Hist Philos Sci 107 (2024): 54–63.
21. Abel DL. Why is Abiogenesis Such a Tough Nut to Crack? Arch Microbiol Immunol 8 (2024): 338–364.
22. Abel DL. Primordial Prescription: The Most Plaguing Problem of Life Origin Science. New York, NY: LongView Press Academic (2015).
23. Einstein A. Sidelights on Relativity. Berlin: Springer (1922).
24. Wigner EP. The unreasonable effectiveness of

mathematics in the natural sciences. Pure Appl Math 13 (1960): 1–14.

25. Hamming RW. The unreasonable effectiveness of mathematics. Am Math Mon 87 (1980): 81–90.
26. Endres RG. The unreasonable likelihood of being: origin of life, terraforming, and AI. arXiv 2507.18545 (2025).
27. Abel DL. The capabilities of chaos and complexity. In: Society for Chaos Theory: Society for Complexity in Psychology and the Life Sciences. International Conference at Virginia Commonwealth University, Richmond, VA (2008).
28. Abel DL. Complexity, self-organization, and emergence at the edge of chaos in life-origin models. J Wash Acad Sci 93 (2007): 1–20.
29. Abel DL, Trevors JT. Self-Organization vs. Self-Ordering events in life-origin models. Phys Life Rev 3 (2006): 211–228.
30. Abel DL. Life origin: The role of complexity at the edge of chaos. In: Chandler J, Kay P, editors. Washington Academy of Science. Lecture at the National Science Foundation, Arlington, VA (2006).
31. Abel DL, Trevors JT. Three subsets of sequence complexity and their relevance to biopolymeric information. Theor Biol Med Model 2 (2005): 29–45.
32. Trevors JT, Abel DL. Chance and necessity do not explain the origin of life. Cell Biol Int 28 (2004): 729–739.
33. Abel DL. Spontaneous Mutations vs. Prescribed Polymorphisms. J Bioinform Syst Biol 8 (2025): 68–82.
34. Abel DL. Constraints vs. Controls: Progressing from description to prescription in systems theory. Open Cybern Syst J 4 (2010): 14–27.
35. Einstein A, Podolsky B, Rosen W. Can quantum mechanical description of physical reality be considered complete? Phys Rev 47 (1935): 777–780.
36. Abel DL. Formalism > Physicality (F > P) Principle. SciTopic Paper (2012).
37. Abel DL. The Formalism > Physicality (F > P) Principle. In: Abel DL, editor. The First Gene: The Birth of Programming, Messaging and Formal Control. New York, NY: LongView Press Academic (2011): 325–351.
38. Abel DL. Assembly Theory in life-origin models: A critical review. BioSystems 247 (2025): 105378.
39. Abel DL. Selection in molecular evolution. Stud Hist Philos Sci 107 (2024): 54–63.
40. Kuhn TS. The Structure of Scientific Revolutions. 2nd ed. Chicago: University of Chicago Press (1970).
41. Abel DL. The Universal Determinism Dichotomy (UDD): Physicodynamic Determinism vs Choice Determinism. Scopus Sci Topic Paper (2005).
42. Abel DL. The Cybernetic Cut: Progressing from Description to Prescription in Systems Theory. Open Cybern Syst J 2 (2008): 252–262.
43. Johnson D. Biocybernetics and Biosemiosis (2013).
44. Abel DL. The Cybernetic Cut and Configurable Switch (CS) Bridge. In: Abel DL, editor. The First Gene: The Birth of Programming, Messaging and Formal Control. New York, NY: Long View Press Academic (2011): 55–74.
45. Abel DL. What is ProtoBioCybernetics? In: Abel DL, editor. The First Gene: The Birth of Programming, Messaging and Formal Control. New York, NY: LongView Press Academic (2011): 1–18.
46. Abel DL. The Cybernetic Cut: Progressing from Description to Prescription in Systems Theory. SciTopic Paper (2008).
47. Johnson DE. Programming of Life. Sylacauga, AL: Big Mac Publishers (2010).
48. Abel DL. Linear Digital Material Symbol Systems (MSS). In: Abel DL, editor. *The First Gene: The Birth of Programming, Messaging and Formal Control*. New York, NY: LongView Press Academic (2011): 135–160.
49. Rocha LM. Evolution with material symbol systems. BioSystems 60 (2001): 95–121.
50. Abel DL. Prescriptive Information (PI). Scirus SciTopic Page (2009).
51. Abel DL. The biosemiosis of prescriptive information. Semiotica 174 (2009): 1–19.
52. Abel DL. The capabilities of chaos and complexity. Int J Mol Sci 10 (2009): 247–291.
53. Abel DL. The GS (Genetic Selection) Principle. Front Biosci 14 (2009): 2959–2969.
54. Shannon C. A mathematical theory of communication. Bell Syst Tech J 27 (1948): 623–656.
55. Kogay R, Wolf YI, Koonin EV. Horizontal Transfer of Bacterial Operons into Eukaryote Genomes. Genome Biol Evol 17 (2025): 4.
56. Jagadeesan R, et al. Dynamics of bacterial operons during genome-wide stresses is influenced by premature terminations and internal promoters. Sci Adv 11 (2025): eadl3570.
57. Maniatis T. From bacterial operons to gene therapy: 50 years of the journal *Cell*. Cell 187 (2024): 6417–6420.

58. Eames M, Kortemme T. Cost-Benefit Tradeoffs in Engineered lac Operons. Science 336 (2012): 911–915.

59. Song Y, et al. Predicting the structural impact of human alternative splicing. Genome Biol 26 (2025): 283.

60. Haltenhof T, Preussner M, Heyd F. Thermoregulated transcriptomics: the molecular basis and biological significance of temperature-dependent alternative splicing. Biochem J 481 (2024): 999–1013.

61. Dai J, Aoto J, Südhof TC. Alternative Splicing of Presynaptic Neurexins Differentially Controls Postsynaptic NMDA and AMPA Receptor Responses. Neuron 112 (2024): 515–519.

62. Wills PR, Carter CW Jr. Impedance Matching and the Choice Between Alternative Pathways for the Origin of Genetic Coding. Int J Mol Sci 21 (2020): 19.

63. Black AJ, Gamarra JR, Giudice J. More than a messenger: Alternative splicing as a therapeutic target. Biochim Biophys Acta Gene Regul Mech 1862 (2019): 194395.

64. Moon J. Tandem repeat disorders: from diagnosis to emerging therapeutic strategies. Encephalitis 5 (2025): 27–35.

65. Lujumba I, et al. A practical guide to identifying associations between tandem repeats and complex human traits using consensus genotypes from multiple tools. Nat Protoc (2025).

66. Homma K, et al. Longer internal exons tend to have more tandem repeats and more frequently experience insertions and deletions. Life Sci Alliance 8 (2025): 12.

67. Ershova ES, et al. Variation in the Content of Three Tandem Repeats of the Human Genome in Peripheral Blood Leukocyte DNA of People of Different Ages (5–101 Years). J Aging Res (2025): 8847073.

68. Doss RM, et al. Mosaicism in Short Tandem Repeat Disorders: A Clinical Perspective. Genes (Basel) 16 (2025): 2.

69. Davenport ML, Swanson MS. RNA gain-of-function mechanisms in short tandem repeat diseases. *RNA* **31** (2025): 349–358.

70. Wu QY, et al. Histone deacetylase HDA-5 regulates lipid metabolism through H4K5 and H4K8 acetylation in *Caenorhabditis elegans*. *J Biol Chem* **301** (2025): 110893.

71. Watt L, et al. Manipulating engram histone acetylation alters memory consolidation. *Hippocampus* **35** (2025): e70041.

72. Wang P, et al. GSK3beta-regulated lipolysis is required for histone acetylation and decidualization in early pregnancy. *Adv Sci (Weinh)* (2025): e14291.

73. Takatoya M, et al. Glutamine promotes myogenesis through glutaminolysis-mediated histone H3 acetylation that enhances myogenin transcription. *Nutrients* **17** (2025).

74. Shirvaliloo M, et al. Exploring the impact of nanotherapeutics on histone H3 and H4 acetylation enrichment in cancer epigenome: A systematic scoping synthesis. *Epigenomes* **9** (2025).

75. Shi W, et al. Mechanistic insights into histone recognition and H3K14 acetylation by the NuA3 histone acetyltransferase complex. *Nat Commun* (2025).

76. Popova L, et al. Acetylation of the histone-like protein HBsu alters gene expression during sporulation in *Bacillus subtilis*. *Front Microbiol* **16** (2025): 1629989.

77. Paz NE, et al. Targeting histone acetylation to enhance somatic embryogenesis in *Quercus suber* L. *Tree Physiol* (2025).

78. Taira A, et al. Carboxylesterase 1d-mediated aglycone recognition is crucial for substrate processing and allosteric activation of endo-alpha-mannosidase in the endoplasmic reticulum. *Bioorg Med Chem* **134** (2026): 118547.

79. Li Y, et al. Differential allosteric modulation of Cas9 specificity. *J Chem Theory Comput* (2026).

80. Kataoka T, Tsuchido Y, Kawai H. Turn-off fluorescence sensing of benzenediols via guest-induced pi-conjugation switching in bisimidazole-based hydrindacene allosteric receptors. *Phys Chem Chem Phys* (2026).

81. Ge Y, et al. GluN2B-specific NMDAR positive allosteric modulation reverses cognitive and behavioral abnormalities in *Mecp2* and *Disc1* transgenic mice. *Sci Adv* **12** (2026): eady3891.

82. Dorbath E, et al. Contact cluster modeling of allosteric communication in PDZ domains. *J Phys Chem B* (2026).

83. Nandakumar J, Cech TR. Finding the end: recruitment of telomerase to telomeres. *Nat Rev Mol Cell Biol* **14** (2013): 69–82.

84. Giardini MA, et al. Telomere and telomerase biology. *Prog Mol Biol Transl Sci* **125** (2014): 1–40.

85. Liu J, et al. Roles of telomere biology in cell senescence, replicative and chronological ageing. *Cells* **8** (2019): 54.

86. Zhong Y, et al. Exercise and epigenetic regulation in COPD. *Int J Mol Sci* **26** (2025).

87. Yang M, et al. WRKY transcription factors: epigenetic and post-translational regulation of plant immunity and growth-environment adaptation. *Plant Cell Environ* (2025).

88. Tao Y, et al. Emerging role of epigenetic regulation in pain sensitization associated with headache disorders. *J Headache Pain* (2025).

89. Sun S, et al. Epigenetic regulation of immune responses and T cells in brain tumors. *Front Immunol* **16** (2025): 1690552.

90. Qin Z, Chen R, Song D. Epigenetic regulation in cardiac developmental toxicity. *Mol Med Rep* **33** (2025).

91. Prasad S, et al. MicroRNAs and long non-coding RNAs in epigenetic regulation of T cells. *Front Immunol* **16** (2025): 1695894.

92. Abel DL, Trevors JT. More than metaphor: genomes are objective sign systems. *J Biosemiotics* **1** (2006): 253–267.

93. Abel DL. What utility does order, pattern or complexity prescribe?. In: *The First Gene*. New York: LongView Press (2011): 75–116.

94. Abel DL. The three fundamental categories of reality. In: *The First Gene*. New York: LongView Press (2011): 19–54.

95. Abel DL, ed. *The First Gene: The Birth of Programming, Messaging and Formal Control*. New York: LongView Press (2011).

96. D'Onofrio DJ, Abel DL, Johnson DE. Dichotomy in the definition of prescriptive information. *Theor Biol Med Model* **9** (2012): 8.

97. Prigogine I. *The End of Certainty*. New York: Free Press (1997).

98. Nicolis G, Prigogine I. *Exploring Complexity*. New York: Freeman (1989).

99. Prigogine I, Stengers I. *Order Out of Chaos*. London: Heinemann (1984).

100. Prigogine I. *From Being to Becoming*. San Francisco: Freeman (1980).

101. Prigogine I, et al. Microscopic theory of irreversible processes. *Proc Natl Acad Sci USA* **74** (1977): 4152–4156.

102. Abel DL. Moving far from equilibrium in a prebiotic environment. In: Seckbach J, ed. *Genesis – In the Beginning*. Dordrecht: Springer (2012): 219–236.

103. Cook J, Pawar S, Endres RG. Thermodynamic constraints on microbial ecosystems. *PLoS Comput Biol* **17** (2021): e1009643.

104. Zhang C, et al. LSP1 as a prognostic biomarker in acute myeloid leukemia. *Biomarkers* (2025): 1–15.

105. Xu S, et al. Dl-3-n-butylphthalein inhibits neuronal apoptosis after cerebral ischemia-reperfusion injury. *Neurotoxicol Teratol* (2025): 107434.

106. Xiong Y, et al. Corynoline promotes apoptosis in glioblastoma via STAT3/Bcl-2 pathway. *Naunyn Schmiedebergs Arch Pharmacol* (2025).

107. Xing X, et al. IRF2-INPP4B pathway aggravates acute myeloid leukemia by inhibiting apoptosis. *Turk J Haematol* (2025).

108. Li X, et al. Porcine epidemic diarrhea virus induces mitophagy to inhibit apoptosis. *Vet Microbiol* **303** (2025): 110427.

109. Schlatter R, et al. ON/OFF and beyond: a Boolean model of apoptosis. *PLoS Comput Biol* **5** (2009): e1000595.

110. Hunt A, Evan G. Apoptosis: till death us do part. *Science* **293** (2001): 1784–1792.

111. D'Onofrio DJ, Abel DL. Redundancy of the genetic code enables translational pausing. *Front Genet* **5** (2014): 140.

112. D'Onofrio DJ, An G. Comparative approach to biological information processing. *Theor Biol Med Model* **7** (2010): 3.

113. Abel DL. The genetic selection principle. In: *The First Gene*. New York: LongView Press (2011): 161–188.

114. Abel DL. The genetic selection principle. *Front Biosci (Landmark Ed)* **14** (2009): 2959–2969.