On the Ontology of Biological Entities*

Part 2: Conceptual or "Mind-dependent" Constituents of the Biosphere

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In the first of two articles on the ontology of biological entities (appeared in *Resonance*, Vol.29, No.8, pp.1111–1126), I had discussed how young students of biology intuitively imagine the biosphere, constructed from the bottom up by physical material entities that act as its building blocks. The nature of being, or ontologies, of these entities, it would seem, depend upon the machination of parts and processes confined within their material demarcating structures like membranes, walls, and skins. I suggested that perhaps there is precedence to this view due to the influence of reductionist and mechanical philosophies upon the early development of biological thought. Additionally, this view is mirrored in the way biology is taught in academic institutions today that could reinforce this part–whole, hierarchical imagination of the biosphere. In this article, I discuss the development of biological thought that took shape in the early part of the 18th century that was influenced by and borrowed from contemporary developments in disciplines outside the natural sciences. It arose primarily as a response to the reductionist and mechanical descriptions of living bodies, and may be seen as a move toward a more holistic understanding of the biosphere. These frameworks bring forth the idea of conceptual unities whose ontologies are dynamic and influenced by changes outside their boundaries. Taken together, both these perspectives are useful and necessary for a student of biology to appreciate the diverse and dynamic nature of the biosphere. A useful guide to understanding material and conceptual boundaries is provided. Once again, I take recourse to Robert Frost's

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poem "Mending Wall" to guide our discussions on the topic.

> **Spring is the mischief in me, and I wonder**
> **If I could put a notion in his head:**
> **'*Why* do they make good neighbors?' Isn't it**
> **Where there are cows?**
> **But here there are no cows.**
> **Before I built a wall I'd ask to know**
> **What I was walling in or walling out,**
> **And to whom I was like to give offense.**
> **Something there is that doesn't love a wall**
>
> **– An extract from Robert Frost's "Mending Wall" [1].**

Background

Imagining the biosphere as whole that is composed of materially bounded parts was common in the early developmental history of biological thought. This was a period when it was not uncommon in the natural sciences, and particularly the biosciences, to operate within principles of ontological and methodological reductionism, first laid down by the classical Grecian philosophers and improved upon by the thinkers of the Renaissance and the scientific revolution of the 1600s. Furthermore, it was quite common then to assume that the biosphere operated upon the foundational principles offered by the physical and chemical sciences. Here, it was assumed that physical and chemical components alone were sufficient in providing the necessary properties of the now self-sufficient building blocks. Some of the more popular academic disciplines in our more recent history, while providing progressively finer lenses with which to view the biosphere, seemed to be guided by the logic of the abovementioned modalities. The hierarchical mereological frameworks provided by this perspective have been highly useful pedagogic tools for early students of biology, while providing a focus of study. Additionally, in the early and middle 20th century, a flurry of activity and progress within molecular biology, especially genetics and the discovery of DNA, may have helped crystallize the reductionist outlook to the biosphere. Such an outlook appears also to have captured the popular imagination concerning themes, concepts, and objects in biology, which still continues to recent times. This was the central focus of the first of the two articles.

However, biological phenomena are dynamic, multicomponent, and multicausal, and sometimes downright chaotic and seemingly unpredictable for simple spatially scaled part–whole discussions of what they are and why they behave in a certain way. The focus of the present article is to highlight discussions in the development of biological thought that provide for alternate but possibly equally important perspectives that seek to answer these questions. Schools of thought that initially arose as a response to the reductionist mechanical perspectives took a more holistic view concerning the nature of biological entities and urged biologists to consider the influence of factors outside material-bounded forms that collaborate to generate very dynamic and continuously changing ontologies of the components of the biosphere.

Taken together, these various perspectives may help fully capture the complexity and diversity of both the constituents and their relationships within the biosphere. What is also discussed is a useful guide as to what is meant by material and/or conceptual boundaries, and what this consideration results in, in terms of how the biosphere is studied and understood. Finally, I discuss a few ways to redress pedagogy and make students aware of situations when they are engaging with material boundaries/entities and when the biological entities are conceptual in nature. Once again, one must disclaim that these articles are not meant as comprehensive historiographies of the philosophy of biosciences. The aim of these articles is to make students aware of different possibilities of discussing the nature of biological individuals and bio-phenomena, and provide context for these distinct organizational frameworks that often tend to influence and inform each other. Additionally, the hope is that teachers of the biosciences who guide students' imagination of the living world will incorporate these contexts in their pedagogies while discussing the nature of the biosphere.

Birth of Biology and the Notion of "Alles ist Wechselwirkung"

The inclination to consider that fates of the living are affected by forces outside of its material boundaries is as old as civilization. Consider for instance how life, disease, and death of an individual, at one point in our history, were viewed as being affected by Divine forces. Even later, when protomedical traditions were discussing these events, they considered the human body to be a part of a larger influential cosmos consisting of both animate and inanimate participants.

Natural historians that immediately followed the scientific revolution of the 1600s had already begun to point out the insufficiency of reductionist mechanical principles as explanations for the properties of life. For a while, in the early to mid-1700s, taking a stand in opposition to "mechanical philosophy" became the norm. Writings from that period, mainly from the German-, French-, and later from English-speaking worlds, resonate with the need to move away from a mechanical self-contained picture of the living world and toward having explanations that were *ad hoc* to bio-phenomena.

One such natural historian, who most early students of biology are familiar with, was Jean-Baptiste Pierre Antoine de Monet, known simply as Lamarck. Lamarck was one of the first to highlight the necessity for a unified discipline that principally concerned itself with providing *la theorie des corps vivans* (translates roughly to "theories of living bodies") and, in 1802, coined the term "biology" in the sense we understand and use it today[1]. Lamarck advocated an improvement upon the existing

[1] There were others before and contemporary to Lamarck who have suggested a need for a separate field of study of "bodies" endowed with the quality of life. These include natural historians and philosophers alike (although one would run in to some trouble clearly distinguishing the two groups). These include Georges-Louis Leclerc – la Comte de Buffon, John Needham, Charles Bonnet, Peter Pallas, Deni Diderot, Erasmus Darwin (whose nephew was Charles Darwin) among others.

part–whole mechanical descriptions of life forms. According to him [2],

> *The "faculte de vivre" (roughly translates to 'the property of life') in reality comes from the particular "aggregation" of elementary particles. This "aggregation" causes, in its composition, the emergence of properties which are not possessed by elementary particles but which arise from the particular way in which they are combined*

Today, we call such properties alluded to by Lamarck as emergent properties of multicomponent systems, a term that is elaborated later in this article.

In the same year as Lamarck, a German naturalist and proto-evolutionary biologist by the name Gottfried Reinhold Treviranus had also used the term in the title of his six-volume work, **Biologie, oder Philosophie der lebenden Natur** (**Biology, or the philosophy of the living nature**) [3]. Treviranus' work comes at the height of, and was influenced by, an intellectual and cultural movement called *Romanticism*, centered in the German-speaking world roughly during the period between 1770 and 1840. In its early phase, German Romanticism, centered mainly in the city of Jena, and drawing inspiration from the philosophical works of Immanuel Kant, Johann Wolfgang von Goethe, Friedrich Schelling, and later G W F Hegel, emphasized that the ontology of man was incomplete without taking into consideration the influence of aspects of nature that one finds oneself in. Early German Romanticism's influence on biology, which gave birth to the school of thought known as *Romantische Naturalphilosophie*, was centered around the concept of *Wechselwirkung* (translatable as "inter-relatedness", "interdependence", or "interplay") that sought to explain the influence of the environment upon the living body. As a consequence, this was also the period that saw the areas that would later be termed as ecology and evolutionary biology break new ground. Romantische Naturalphilosophie developed as a counternarrative to reductionism *and* mechanistic natural philosophy, and considered that the features and properties and indeed evolutionary success of an organism are deeply influenced by the context of the environment that it finds itself in; or *nature in total*. One very influential thinker belonging to this school was the German naturalist Alexander von Humboldt. Humboldt, while on his expeditions across south-central America, observed that the distribution of plant life was closely related to geological and geographical factors, which inspired his quote *Alles ist Wechselwirkung* (translatable as “everything is interrelated”) [2]. These ideas lend credence to the possibility that the ontology of the living body will depend on aspects external to its material boundaries and that a holistic view is better suited to explain the nature of its being.

Some of the early British natural historians were greatly influenced by the German Romantic natural philosophy and alluded to the influence of external factors on the ontology of biological entities. Among them were the front runners of the field we now know as evolutionary biology: Charles Darwin, and his contemporary, Alfred Russel Wallace, who urged a revision of the machine-life description of bio-phenomena[2]. For Darwin, continuous change was the fundamental nature of the living world. This is relevant in the context of our present discussion and for

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[2] It would appear that Charles Darwin was also an early pioneer of the interdisciplinary approach that has become a buzzword today. His ideas on the aspects that governed the origin of species were influenced by his readings of Charles Lyell (a Geologist, studying rock formations) and Thomas Malthus (an Economist who wrote on the interplay between populations and resources), and by his close familiarity with the works of breeders and medical scientists (like Prosper Lucas) on the issue of heredity. Darwin was hugely influenced by Humboldt, and at one time even copied his writing style. So too was Ernst Haeckel, the other great evolutionary and holistic biologist of the late 19th century. Moreover, Darwin and Haeckel also influenced each other a lot and the latter was instrumental in popularizing Darwin’s theory of evolution in Germany. It may be of interest to the reader that around 1838 Belgian mathematician Pierre Verhulst, reading Thomas Malthus’ work, developed what would later be termed the “carrying capacity” of the environment, in other words the maximum population size of a particular species that an ecological niche can sustain. It should be noted that the notion of carrying capacity is now considered obsolete.

its time for two important thrusts: one, that there was no appeal to the Divine as far as the ontology of an organism is concerned; and second, that ontogeny was neither teleological (goal or purpose directed) nor just algorithmic. This is most evident in the discussion on one of the cornerstones of Darwinian thought: adaptation.

To contextualize, adaptation is a spatially and temporally continuous process where materially bounded individuals of a collective who can reproduce sexually (read: species) vary in their heritable ability to survive and reproduce in the face of the constraints imposed upon them by a conceptually bounded component of the larger environment that they inhabit (read: a niche). Organisms accomplish this because they exhibit many heritable variations among individuals (read: diversity) within a population. Individuals exhibiting one or some of these inheritable variations may be able to overcome the constraints in the niche (read: survival of the fittest: an unfortunate and confusing phrase, prone to severe misunderstanding) and consequently become more frequent in the population (read: natural selection) and subsequently carry on propagation. With time, new variants may be generated with the potential to overcome fresh constraints (if present) in the niche. Clearly, the ontology of the individual that survives and therefore deemed the fittest is also determined by objects, processes, and influences outside it.

At this point, we must also be conscious of the effect that the organism could be having on the environment. Here, certain functions and properties of the organism, such as metabolism and replication rates for instance, can affect the niche and thereby render *it* changeable as well[3]. Consider for instance Darwin's

[3] In philosophy, a method that studies the relationship between phenomena and their mutual impact on each other is called dialectics. A version of this developed by Karl Marx and Friedrich Engels, as a response to the post-Kantian German philosopher Hegel, and called dialectical materialism, has had a significant impact on biologists and philosophers of biology including Needham, Bernal, Haldane, and Waddington mentioned later in this article. Dialectical materialism also inspired the Modern Synthesis

own work on earthworms which spanned nearly 40 years and culminated in his 1881 book titled **The Formation of Vegetable Mound through the Action of Worms, with Observations on their Habits** [4]. His observations on how the activity of earthworms modified soil in which they grew would later be foundational to Bioturbation, a process by which soil properties are influenced by the activities of living matter that inhabits them. Bioturbation is known to be an important driver of ecological biodiversity.

The Organicistic Perspective

The German Romantic Natural philosophic tradition noted above suggested that a cooperative model must be envisaged where the nature of the organism is always in flux because of its often changing external environmental and ecological contexts, both in time and in space. This meant that the nature of the organism, in terms of its features and functions, cannot be built around mechanistic instructional algorithms alone. Such a way of thinking soon began to influence the understandings of natural historians in the English-speaking world. The later biologists espousing this more holistic view were came to be known as the *Organicists*. The term was first referenced by the British physiologist John Scott Haldane in the late 1800s and early developmental biologists such as Ross Harrison, Joseph Needham, and Paul Weiss in the early 1900s [5]. The term was taken up again in the 1930s by the members of the "Theoretical Biology Club"[4] as continued opposition

model of evolution, a reconciliation of the genetic paradigms of Mendel and Thomas Hunt Morgan, and the evolutionary paradigms set out by Darwin and Lamarck among others.

[4] Here, the reader is directed to Erik L Peterson's 2016 book [5] and especially to the influence of mathematician and philosopher Alfred North Whitehead's works on the members of the Theoretical Biology Club. A N Whitehead's metaphysics, while fairly obscure in its presentation, urged one to consider the world (and the cosmos) as a part of an inter-related web of processes. Whitehead is also known to be a big influence on the process philosophers of biology discussed later in the article. The members of the Theoretical

to the reductionist and mechanicist perspectives and also to a very influential development at that time – the gene-centered view of biology. Members of this club included Joseph and Dorothy Needham, Joseph Woodger, J D Bernal, and Conrad Waddington [5]. While the organicism framework retained the basic understanding that molecules and cells were multicomponent collections whose functions contributed toward synthesizing the whole, there were two important features that kept it apart from the mechanicism perspective. First, the organicism model scaled phenomena four dimensionally in space *and* time, rather than space alone. Second, and more important for our further discussion, the organicist thinking that coalesced in Conrad Waddington's 1957 work **The Strategy of the Genes** posited that the status of an organism as a unified whole is temporary and can only be fully understood if one takes into consideration the following four unifying perspectives: genetic, physiological, developmental, and evolutionary [6]. Waddington noted that each of these aspects operated within the time frames of their own and variously influenced the ontology of a biological entity. Even the contributions by the internal aspects to the bounded limits of the organism depended on the number and nature of influences between its constituent physical components. As the popular adage goes, the whole it would seem is always greater than the sum of its parts[5,6].

Biology Club were also the first to articulate the possibility of epigenetic phenomena involved in gene expression and its regulation and consequently generation of phenotypes, later expounded by Israeli geneticist and evolutionary biologist Eva Jablonka.

[5] A group of thinkers worth mentioning are, the Gestaltists, to whom this phrase is commonly attributed to, and whose work was primarily in the field of psychology with specific concerns about human perception and cognition. Gestaltism, like Organicist metaphysics, also has roots in the philosophies of Immanuel Kant.

[6] About 6 years after the publication of **The Strategy of the Genes**, Dutch biologist and ornithologist Nikolaas Tinbergen developed a model similar to Waddington's to understand animal behavioral responses. He posited that the

Cooperation, Collaboration, and Coexistence

The understanding of the interplay between an individual organism and the environment could now be extended to the collection of diverse occupants of the niche. Their *collaborative agency* rendered the ontology of the niche in constant flux. This in turn fed back and affected the ontology of every single one of its occupants. Now imagine if the niche itself was a living organism. What was then actually being selected? Was it the species or the collective of species, or was it the niche itself that continued its occupation of space–time? What was it that was actually evolving? In other words, what must be *walled-in*, in this case?

It was discovered that some of the collaborative influences between organisms, for instance, were quite critical for the survival and stability of either one, or all, of the interacting organisms: as individuals or collectives. There are several versions of organismal interactions and necessary conditions/qualifiers that describe them: mutualistic, commensalic, predatory, and so on. One such condition is one of obligatory cooperation and collaboration that benefits all the interactors, and results in coexistence and even their collective evolutionary survival: symbiosis[7].

An important name in the discussions on boundaries and symbiosis is Lynn Margulis. She introduced two important concepts that necessitated the reconsideration of spatial limits and ontology of beings: *the serial endosymbiosis theory (SET)* and the *holobiont* [7].

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behavioral response elicited by animals is a combination of innate instinctual behavior and spontaneous behavior specific to the external stimulus to which the animal appears to be responding. For the study of individual vs social behavior patterns, Tinbergen shared the 1973 Nobel Prize with Karl von Frisch and Konrad Lorentz. Together, they are considered the founders of the field of study called ethology.

[7] Symbiosis can be translationally deconstructed more accurately to: *sym-* (together) and *-biosis* (living).

In SET, it is conceived that contemporary eukaryotic cells were a consequence in time of prokaryotes internalizing other prokaryotes. The result was membrane-bounded entities (compartmentalizations) inside a larger membrane-bound entity. If this cohabitation arrangement was mutually beneficial, then in time, what manifested were membrane-bound cellular organelles that divided life labor. The sum total of all these now internal interactions was the *eukaryote*. A case is made for the nucleus on one hand, and the mitochondria and the chloroplast on the other having evolved as endosymbionts; the former is a principal site/locus of replication and the latter for cellular respiration and energy capture, respectively[8]. The point here is that we have come to consider, at a cellular level, membranes as the ultimate defining demarcator where the cell is *the organism*. However, the SET urges biologists to reconsider this paradigm in evolutionary and developmental time frames. In this case then, the resulting eukaryote is akin to a biotic niche.

Expanding this microcosmic view of the eukaryotic cell in spatial scales, it would appear that cooperative existence permeates the entire biosphere, from cells to populations, and is vital for the survival of all its components. The term Margulis later used for smaller conceptually bounded units of the biosphere was the *holobiont*. Take for instance, the crucial and almost inseparable role that microorganisms (bacteria for instance, and sometimes also bacteriophages that subsist in them) play in life-affirming properties of human hosts, and vice versa, forming a multipartite existence. What is now known is that the microcosm of this relationship has its own evolutionary and developmental histories. It is easy to see that the demarcations in both the SET and the holobiont perspectives are that of conceptual boundedness of unities. Here, the ontological agencies are local and inter-relational and go beyond material boundaries that demarcate an entity.

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[8] Nuclear division is one of the earliest processes in the cell division enterprise, and the mitochondria and the chloroplast have abilities to replicate autonomously, each containing their own genetic material, comparable in sizes to some smaller contemporary prokaryotes.

Biological Networks, Systems, and Emergent Nature of Living Things

The middle and late 20th century witnessed some crucial developments that profoundly impacted how we now discuss biological phenomena, both in theory and in ontology. First, there was a concerted move away from reductionism that stemmed from the realization that newer frameworks were needed to study complex collaborative multicomponent ontologies. Second, progress in digital technology enhanced the speeds and scales at which information can be acquired, compared, analysed, and shared. *Network science* was the name of an organized domain that took advantage of this development and was first deployed to study social phenomena.

These new developments opened up some refreshing ontological possibilities for modern biologists[9]. Sophisticated, and quite literally and metaphorically, out-of-the-box representations and discussions of the living world were now possible.

When biological phenomena were studied through the lens of network sciences, it gave further credence to the fact that collaborative agencies are in operation upon and within every object of the biosphere cutting across spaces, categories, and even conventional hierarchical levels. The biosphere indeed can be usefully conceived as operating like a network. Additionally, the ontology of bio-phenomena, at every spatial scale, appeared to be fundamentally dependent on the number and nature of influences the components of the phenomena had on each other, something alluded to by earlier natural historians like Lamarck. Such an understanding provided biologists with the tools not just to study the dynamic nature of biological phenomena, but also to, at least theoretically, predict and control their dynamicity. We

[9] It needs to be noted here that the rudimentary conceptual network-like frameworks such as "food webs" can be seen in the literature around the late 1800s, notably by the Italian entomologist Lorenzo Camenaro.

now know this field as network or systems biology. Here, a very important term that is used to discuss the behavior of biological systems is *Emergence*. Emergence is not only useful in discussing the ever-changing nature of bio-phenomena but also their apparent stability in the face of the ever-changing environment (often referred to in biology as *homeostasis*[10]). Emergent behavior of bio-phenomena studied as networks or systems is the behavior that cannot be extrapolated from the systems' components alone, but is the outcome of (*emerges* out of) the number and nature of interactions between the components of the system; the system and the environment; and between systems that constitute higher-order organizations. The unifying principle (or the *self*) of such a system does not arise from physical material spatial boundedness but is conceptual.

Let me illustrate this with an example from immunology, which became an organized discipline in the early 1900s. Some of the earliest treatises on immune function were first elaborated by Elie Metchnikoff and Paul Erlich, who were studying how certain leukocytes responded to the presence of pathogens. Cellular engagements with pathogens, such as phagocytosis by myeloid cells and T cell-mediated cytotoxicity, are still considered central to immune function. Since then, the discipline has grown to include several other cell types (such as other myeloid cells, lymphocyte types and subtypes, and so on) and soluble particles (such as antibodies and cytokines) as agents of immune response. What is interesting is that engagement of the same cells and soluble agents and similar pathogens elicit a variety of outcomes, including favorable and unfavorable ones. It soon came to light that to fully understand this possibility, these cells and molecules had to be studied as a system, and it is the number and nature of interactions across conventional spatial levels that decided the outcome of the response. We now know that this immune "system" itself

[10] It is interesting to note that when physiologist Walter Canon who conceptualized homeostasis in the mid-1800s, he discussed it in terms of internal features and processes that maintained organismal steady states. His preferred term was "internal milieu".

comprises two subsystems called the cellular and humoral systems, and each influences the behavior of the other. Notably, and relevant to this discussion, by the mid-1960s and 1970s, two Nobel Prizes were awarded that brought forth a conceptual network model of immune function. McFarlane Burnett's work on the cellular immune system and Neils Jern's work on the humoral system each highlighted how immune response must be considered an emergent phenomenon and not just the outcome of cell–pathogen interactions. Additionally, it also became apparent that cells like epithelial cells and even local microbial flora, two cell types that would otherwise may not have been seen to be included by conventional demarcation standards, contribute significantly to immune system function and development. Furthermore, contemporary immunology views that other systems, such as the neuronal and the endocrine, to name a few, significantly contribute to the nature of immune homeostasis and/or responses to pathogens.

Biological Phenomena as Processes

These days, in the philosophy of biology, some interesting questions are being taken up that concern the very foundations of the ontology of bio-phenomena. For instance, can processual change be considered more fundamental than the apparently stable materials/substances in the construction of the living world? Or, can time rather than space provide for a better scalar framework using which we can more meaningfully conceptualize biological phenomena[11]?

This *process philosophy of biology* urges one to reconsider not just the ontological descriptions that use any kind of material spatial boundedness, but also epistemology, i.e., the knowledge we generate regarding bio-phenomena and the means of generating

[11] Within materialist thought, time is seen as subordinate to space and as something that arises consequentially to changes in space – take for instance a day described as "the time taken for the completion of one rotation of the planet".

it, and even the very vocabulary in use in the discussion of our understanding of bio-phenomena[12].

Among the contemporary thinkers who are considered more influential in bringing processual thought to life sciences are John Dupre and Daniel Nicholson (presently with the University of Exeter, UK) and Anne-Sophie Meinke (University of Vienna, Austria). In the introductory chapter of a 2018 book, **Everything Flows – Towards a Processual Philosophy of Biology** (the book also features a wonderful essay by A-S Meinke that looks at humans and human identity as processes), Dupre and Nicholson (who are also the curators and editors of this book) provide a foundational framework for understanding biological phenomena as processes. The reader is directed to the introductory chapter of the book which succinctly illustrates, using three aspects crucial to the property of life – metabolic turnover, life cycles, and ecological interdependence – how processual ontology can improve upon conventional substance- or material-based ontological considerations of life.

Within a processual framework, life (or its component parts) does not merely exist, it is continuously in a state of becoming; not living beings but living *becomings*. What are perceived as substance or material are but manifestations of temporally stabilized processes: *eddies in a flowing river*[13] during empirically/sensorily driven investigations. Therefore, processes become more fundamental than materials at any level of construction. Unlike conventional wisdom, a process is not something that happens to

[12] In a paper published in 2021, John Dupre and co-author Sabina Leonelli discuss the recent COVID-19 pandemic under the lens of what they call *process epistemology*. Here, the authors talk about, among other things, "data", the cornerstone of any scientific investigation as but a temporally stabilized snapshot of a larger processual phenomenon that a scientist chooses as a reference point in her investigation [8].

[13] Use of the analogy of rivers perhaps is an homage to Heraclites, a pre-Socratic Greek philosopher considered the father of processual thought and an adage that is attributed to him *You can't step into the same river twice*, alluding to the changing nature of the river, and perhaps also of "you!"

or because of material objects, but rather that processes generate or more precisely *appear* to the investigator as materials when she engages with them at specific points in time. This is what sets the processual paradigm apart from the network ontology paradigm of bio-phenomena discussed earlier that continues to work with substantial/material components and their interactions. At any given point in the scale, these stabilized processes in turn arise from other lower-order processes and subsequently become (temporal) parts of higher-order processes. In resonance with the O&P model, there exists rather a hierarchy of processes[14]. The overall emphasis is on "change" rather than "stasis", and consequently, time rather than space becomes more useful reference in discussions of scale. These are important assumptions that inform our decision to attach spatial limits or material boundaries to biological phenomena [9].

On Material and Conceptual Boundaries

All things so far considered, a student of biology must be cognizant of a di-lemma[15] similar to the one faced by Robert Frost in Springtime as he sat down to mend the winter-worn wall. This structure once physically demarcated his property from that of his neighbor. The latter, a creature of tradition and habit, insists that such material demarcations bring clarity and facilitate the agency of the occupants. The poet on the other hand wonders if the agencies of said neighbors must indeed depend on such structures, and if it did, wouldn't it be prudent to pause and take stock of *why* this is so?[16] While discussing conceptual entities, it is preferable

[14] Or more accurately a network of *process relational agencies.*

[15] Intended pun – *lemma* in Greek refers to outer covering, such as a rind, in other words, a boundary. Dilemma is a situation with two possible alternatives. Could we reimagine our use of the word to mean two possible boundaries?

[16] Robert Frost was a pioneer modernist poet who once famously reflected that his poetry was like *tennis played without a net*. His poems are at once literal and symbolic.

to discard the shoes of the neighbor and put on the hat of the poet.

When Frost was penning his work, Europe was in the middle of the First World War. The boundaries of old kingdoms were in flux. An important consequence of the war was the generation of the first European "nation-states" as we know them today, from erstwhile kingdoms. A "nation-state" is a curious, but nonetheless useful, political unity. This is because the state as we know is represented by strict geopolitical borders, and nations, as Benedict Anderson would later describe, are *imagined communities*. Its ontology is dictated by the collective minds and imaginations of the populace that shared common histories and cultures.

In 1995, in his article discussing the construction of geopolitical demarcations, **On drawing lines on a map**, the formal ontologist Barry Smith introduces two concepts that may be useful for students of biology in resolving this dilemma [10]. Smith uses the terms *bona fide* and *fiat* boundaries that help with spatial demarcation.

Bona fide boundaries are naturally occurring *boundaries in the things themselves* and exist independent of the cognitive or conceptual faculties of the observer. Membranes around cytoplasms or solid organs, the skin, and so on may be considered bona fide spatial demarcations. In the absence of such specific structures, discontinuities in homogeneity of material construction can also inform bona fide boundaries, e.g., bony structures. In self-standing materials, bona fide boundaries are akin to surfaces. In chapter 2 of Dupre and Nicholson's book, Peter Simons[17] uses the term *persistents* to discuss homogeneity of material objects that may assist in the discussion on bona fide boundaries in the absence of specific demarcating structures [7].

[17] It may be interesting to note that both Peter Simons and Barry Smith were contemporaries and pursued their doctoral degree in metaphysics under the same supervisor at the University of Manchester, Wolfe Mays.

A persistent is an entity that exists in space and time, exists for – or at – more than an instant and at any time at which it exists has a spatial location and at any instant that it exists, it is identical with the maximal part of it[18].

Fiat boundaries are artificial and *owe their existence to human decision*. These are cognitive or conceptual spatial demarcations, non-physical and are observer dependent. Imagine for instance the ontology of the immune system – the network of cellular cross-activations during immune response, ecological niche containing symbionts, or the susceptible population in disease epidemiology may be demarcated. The natural consequence of the existence of bona fide and the construction of fiat boundaries are *bona fide entities* and *fiat* (conceptual) *entities*, respectively.

Processual ontology of biological phenomena also employs demarcations, but here time rather than space becomes the metric used. Simons uses the term *occurent* or *perdurant* to discuss temporally homogeneous entities if one is interested in constructing boundaries to processes.

Discussion

It is natural to be curious about life phenomena: either casually or as students of the various organized disciplines critically studying it. It is after all something that is exclusive to this planet we cohabit. Biosciences are often looked upon to bridge the invisible world of the hard sciences and the seemingly very cognizable realm of the human and the social realities. We can be coerced into thinking that the living world is constructed bottom up or inside out by equally cognizable component materialities. From here, it is easy to assume that these parts have independent and autonomous existences.

[18] Or as Aristotle states in **Metaphysics**, *"the first point beyond which it is not possible to find any part, and the first point within which every part is"* [11].

Like we have seen so far, the application of material or conceptual boundaries results in the *becoming* of those kinds of entities. Such entities are then amenable to categorization, based on stable and distinguishing properties we apply to them. We can also be led into thinking that these properties are unchanging and essential to the entities that occupy these categories. There are common and often dangerous consequences of inculcating a habit of reductionist and sometimes simplistic part–whole understanding of the living world. This is the tendency, in both an ontological and functional sense, to assume linear or direct relationships between lower-order components and higher-order manifestations in phenomena. This is particularly true at the level of common sense and early career biology students. Take for instance the popular and sometimes even academic discourses on topics as diverse as single nutrients and metabolic diseases, genetic predispositions to human behavior, or the material construction of biological sex. Such extrapolations seldom take into consideration that biological phenomena at any scale are necessarily complex, multicausal, emergent, and in a state of constant flux, and these are but one of the many relational agencies of higher-order phenomena. In metaphysics, this is termed a "category mistake"[19]. What may be interesting to note is that the term was coined by the 20th-century philosopher Gilbert Ryles in his 1949 work, **Concept of the Mind**. He discusses this in the context of causal extrapolations made between the material components of the brain, the central nervous system, and the more abstract conceptual entity, the mind [12].

Provided below, are a few pointers that may be helpful in alleviating this situation among early learners of the life sciences.

Contemporary bioscience education, especially in the formative years has continued largely to adhere single-mindedly to

[19] In a stricter sense, the term may be described *as the tendency to assign simple material realities to complex abstract concepts*. For a more comprehensive account, see Plato Stanford entry from 2019 on **Category Mistakes** [13].

methodological and/or ontological material reductionist frameworks and these alone. This impacts the way students of biology imagine the biosphere exists in reality, making them miss the forest for the trees, both literally and metaphorically. Things can be exacerbated if students are not actively acculturated away from conflating representations with reality. Investigators have always studied natural phenomena by placing windows and lenses upon them – consciously or unconsciously, literally or metaphorically, materially or conceptually. A crucial part of the scientific process is the use of models to study natural phenomena. Models are limited and controlled abstractions of the phenomena. A useful text to illustrate this is the article titled **The role of models in science** by Arturo Rosenblueth and Norbert Wiener. In this article, the authors make pertinent observations that models can either be material or conceptual [14]. The scope of the study and, consequently, the choice and dimensions of the model will be determined by the scope of the questions we choose to ask about the natural phenomena. In the end, knowledge construction in the sciences is collaborative, and each scientist or a group working with a model is working with a box. The dimensions of the box are determined by the design of the study, i.e., its scope. Completion of the work is akin to opening of the box, the knowledge so revealed becoming a part of the design of a larger box or a smaller one contained within it[20].

Biological phenomena present an additional problem of literal and very real box-type presentation, i.e., the presence of material spatial boundaries. A student of biology is typically intuitive about these things, often at the expense of context.

Something else that confounds this problem is the non-textual representations in life science literature. A very crucial component of texts that contribute to the student's imagination of bio-phenomena are pictures and diagrams. Such representations

[20] See S Surendralal (2023) for useful suggestions toward incorporating Rosenblueth and Wiener's article and teaching the role of models in science education among early learners of the discipline [15].

Figure 1. The image on the right is the dynamic representation of cell division by G Anderson, *et al.* Here, cellular energetics during cell division is rendered in purple, chromosomal events in yellow, and cellular/membrane events in brown. The G2 phase of mitosis is at the bottom, moving upward and culminating with cell division at the top. Compare this with conventional representation of cell division on the left; the top panel is Walther Flemming's drawing from 1888, the middle panel is stained snapshots of various individualized "stages" of cell division, and the bottom panel is a diagrammatic rendition of the above.

can often lead to the generation of a static componential view of the living world that persists among students. Some of this is offset by the substitution of learning with animated visual content. However, this may be limited by affordability and digital literacy and/or accessibility. However, some interesting recent engagements have attempted to address this and can also serve as a means of introducing processual thought to early students of Biology. Incidentally, both assume an inter- and trans-disciplinary pedagogic form.

A team comprising John Dupre (a philosopher of biology), Gemma Anderson (an artist), and James Wakefield (a cell biologist), all at the University of Exeter, has recently collaborated on a project that attempts to pictorially represent bio-phenomena as processes in a single image, as an attempt to *communicate the dynamic nature of biological processes and in generating new insights and hypotheses that can be tested by artists and scientists*. They have depicted the process of cell division by mitosis, which conventionally is represented by images or stained pictures of a series of snapshots of the various stages of the process. This, they say, has virtually remained unchanged since it was first presented in this form by Walther Flemming in 1878. This transdisciplinary work was published in the journal eLife in 2019 titled **Drawing and the dynamic nature of living systems** (*Figure* 1) [16].

Anthropologist and science and technology studies scholar Natasha Myers, in her book from 2015, **Rendering Life**

Molecular, discusses various alternative ways of representing and teaching the concept of protein folding [17]. In an earlier work almost a decade earlier titled ***Performing the protein fold***, she discusses a collaborative effort between performing artists, molecular biologists, and engineers that produced a physical staging of the process of conformation acquisition of proteins, elaborating on the various interactants and nature of their interactions that contribute to this emergent process using the human body in performance [18].

Finally, it is vitally important to include discussions on the philosophical, historical, and social contexts of the natural sciences as a whole and perhaps specifically relevant to the life sciences within the undergraduate curriculum. The inter-, trans-, and multidisciplinary turn within undergraduate programs is a welcome opportunity to engage with just this. However, care should be taken that even here, the cross-disciplinary engagement is not merely among academic disciplines that are already walled in within the natural sciences. With access to themes from the social sciences, humanities, and arts, understanding of the sciences and natural phenomena through it can come from the outside-in as well.

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Suggested Reading

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