Biology.

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Biology

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1. Introduction

Biology is the science of life. It examines the materials and processes of life in its varied forms of existence, from the smallest molecular interaction on a gene, to the large evolutionary changes of animal morphology across millennia. Biology[1] is an enormous field that encompasses many schools of thought and many more research disciplines.[2] For example, microbiology is concerned with micro-organisms such as yeast and bacteria; protistology deals with the branch of the unicellular proto-animals; plant biology encompasses all studies on plants and plant growth; developmental biology examines the features of ontogenesis, including genetics, molecular, and cell biology; molecular biology pays attention to gene function in the cell; cell biology to the anatomy, biochemistry, and divisions of labor within the cell; evolutionary biology to the phylogenetic development of the forms and functions of genes, gene products, cell types, and whole organisms over the course of many thousands of re-iterative generations together. Basic biological research contributes to our understanding of the materials and processes of life's functions from the molecule through the cell, to the structures and functions of whole, living organisms.

What life actually is is another question altogether.[3] Biological research aims to define the substances of living things, their characteristics, and their inter-relations, but what life *is* is still unclear. The recognized biological characteristics are the cell (the simplest living unit), self-formation (ontogenesis), and reproduction (heredity), all of which exist and continue to exist in processes that create "living" order out of "dead" disorder. Living things have "negative entropy": they exist at a sustained higher energy state than their surroundings and in doing so defy the second law of thermodynamics. Life therefore represents the transformation of energy from disorder to a sustained order. Life is all of these things, and perhaps more. Whitehead suggests that *experience* is also a part of life, yet this is a philosophical notion that is difficult to explore in mainstream biology itself.

Biology is strictly a modern science and in that sense it is a pragmatic one, and is not philosophical. A strict adherence to the scientific method lies at the heart of the biological sciences; it is the only acceptable form of data acquisition and ties biologists to an empirically driven, verifiable view of *external* reality. Biology is not concerned with features of phenomenal experience, but it prides itself on a strict materialism where third-party observations of biological form and function are the exclusive basis for a world-view. A mechanistic, material determinism forms the dominant philosophical position by proxy,

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underpinning interpretations of biological data and theory. Interestingly, biologists commonly do not consider theirs to be a philosophical position at all, but rather they view their method as uncovering *reality itself*, testable and verifiable through quantitative empirical research. Matter, such as ions, proteins, and nucleic acids, is treated as passive and predicatively reactive. The behavior of materials in living things is therefore investigated according to mechanical, "clock-work" models of causal relations. Modern informatics and complex systems approaches, though more sophisticated in their principles, do not differ from other models in their underlying assumption that a material determinism identifies truthfully "what there is." Organisms in biology are treated as complex arrangements of passive reactions arranged in biologically "functional" networks.

Perhaps due to the remarkable technological applications of a deterministic biology, any serious philosophical alternative to determinism seems difficult for most professional biologists to accept. This discrepancy between science and philosophy is long standing. Loeb remarked, "Science is not the field of definitions, but of prediction and control" (1916, vi). In other words, Loeb was suggesting that science is not philosophical, but is geared for industrial means. Materialism has been remarkably successful at advancing our understanding and useful manipulation of nature. Using the Newtonian conception of matter and the scientific method for verifying experimental phenomena, biology has excelled in its ability to grasp defining characteristics of living organisms. The benefits of this knowledge contribute significantly to the betterment of society through their application in medicine, veterinary medicine, animal husbandry, and agriculture. It is hard to argue that an alternative philosophical position, such as Whitehead's, might be appropriate to consider, especially when one considers that the marvels of modern biomedicine made possible by the mechanistic outlook. Surgeons can replace a failing heart, mend debilitating neurological dysfunction, and safely remove a potentially fatal carcinoma. These operations would not be successful without an in-depth understanding of the mechanisms of life, from the molecular detail of immunoreactivity to the gross physiological conditions necessary for sustained vital function. Biological knowledge has built modern medicine and further contributed to societal well-being through increased agricultural yields and prophylactic health measures such as vaccine, hygiene, and sanitation.

As a form of "prediction and control" biology is an immensely satisfying body of knowledge. However, something remains unsatisfactory and the pragmatic logic of a material determinism cannot overcome one's personal *feeling* of what it is to be alive. And perhaps this is what is missing. Biology knows nothing of *feelings*, yet they are inextricably, unequivocally, undeniably a feature of our natural world. We know they are, because we are them; they are our experience of the world.

2. Whitehead's Philosophy of Organism

Whitehead envisaged everything in the world, all the multitude of entities from subatomic particles to molecules and men, as "organisms" in their own right. In his famous dictum, "Biology is the study of the larger organisms, whereas Physics is the study of smaller organisms" (*SMW* 145), Whitehead sums up his conception that all aspects of nature, even the apparently inanimate particles of matter, are active self-determining entities each with its public and private aspect, and each existing in physical and mental space, insofar as all organisms are. This remarkable shift in position was very much opposed to dominant scientific thought at the time, and remains so today. Matter was and is treated by science as dead, insentient, and predicatively reactive. Whitehead's philosophy of organism turns this notion on its head and considers instead that what we know as matter is a prehended *feeling* of the objectification of another subjective center. "Actual occasions" of *experience* are the fundamental units of the world, not quarks or atoms or cells, and actual occasions are *felt* experiences that extend over time expressing at least some degree of *self-determinacy*.

For the sake of a quick introduction to his philosophy of organism, here it is in a nutshell. Imagine that nothing exists except for a single atom, which is you. What is your experience of the world? You have none, because there is nothing to experience. In fact, one might be tempted to say that you do not exist at all, if existence requires some form of experience. Now, let's place another atom next to you. What are you now? You are now the totality of your interaction with that other atom. Your experience of what you are and what the world is is all that you are, in relation to all that that other atom is. A student of Whitehead summarizes this line of thought: "Actual entities arise out of their prehensions of each other; this secures the solidarity of the order of nature. But they have also their private and unique side, since each organizes its prehensions of the rest of the world into the forming of its own 'real internal constitution' in its peculiar way" (Emmet 1966, 89). Thus, the actual entity (synonymous for actual occasion) is not merely material, but carries with it some organic qualities. It is the "growing together" of many things into a new unity; "the many become one and are increased by one," (*PR* 21 [31]); it is a "unit of becoming" (*e.g. PR* 26 [38]); and it acts with an immanent teleology toward "satisfaction" (*e.g. PR* 26 [38]). An actual occasion is a fundamental "drop of experience" (*PR* 18 [28]).

For the biologist, Whitehead draws on features of biological organization viewed from the *experience* of each part, with an eye to its contribution to the whole. Actual occasions are experiential moments that are viewed as the fundamental "building blocks" of the universe. What we have come to know of as "atoms" and "molecules" can be further analyzed as small societies of actual occasions contributing to a greater envelope, such as a "macromolecular complex" or "protein," "cellular organelle," or "whole cell." Working up in scale we can see that "cells," "cell systems," and "whole organisms" are also societies of actual occasions, each experiencing its world at its level of existence with the uniqueness of its own character, its own physical composition. Each of these levels or organizations can be explained in terms of the coming together of "nexūs" of actual occasions into more complex forms.[4] Thus, in Whitehead's ontology each of these levels of biological organization are not simply physical but have some characteristics of mind also.

Whitehead's philosophy of organism helps to define biological organization in terms of the hierarchical structure of nested relations within living systems, where systems exist within systems, which exist within systems and so on. As Chakraborty writes:

> The physical particles are in the atoms, the atoms are in the molecules, the molecules are in the colloidal aggregates, the latter are in the living cells, the cells are within the organs, and these again within the living bodies, and finally the bodies are within the social aggregates, of which there are aggregates of aggregates (1997).

Relational, nested organization is a hallmark of biological systems. In Whitehead's terms, "a molecule is a subordinate society in the structured society we call 'the living cell'" (*PR* 99 [151]).

3. Whitehead's Philosophy of Organism in Biology

3.1. Cultural Differences

There are some major obstacles blocking the incorporation of Whiteheadian process thought into mainstream biological thought, not least of which is the taboo against considering "mind" as a feature of anything but the human cerebral cortex. Whitehead's concept of the "fallacy of misplaced concreteness" (*SMW* 64, 72) is unknown to the biological community, precisely because the biological community is not a philosophically oriented one, but is rather a pragmatically oriented one. The philosophy of organism also tends to downplay mechanism, or rather it couches it in such abstract terms and references that it becomes unrecognizable. Biological mechanism is a clear feature of existence and is readily accessible to experimental manipulation. The distinctly Whiteheadian features are clear features of existence as well, but they are intangible and teleological. Intangible notions cannot easily be probed, and teleology is marred by loose associations with an impracticable ultimate divine purpose. In the culture of competitive biological research, the intangible, the teleological, and the divine are subjects to be avoided. They are, for all intents and purposes, not testable and therefore untenable. This places them outside the realm of biology, which should instead work on tangible, mechanical problems.

Whitehead's means of articulation also renders his ontology largely inaccessible to scientists raised on a very different culture of language and ideas. Simply put, most biologists do not have the time or inclination to study a philosophy of esoteric notions such as the "Category of the Ultimate," eight "Categories of Existence," twenty-seven "Categories of Explanation," and nine "Categoreal Obligations" (*PR*, 18-30 [27-45]), not to mention "prehensions," "actual occasions," "nexūs," and "structured societies." Whitehead's language seems very remote to many biologists, who are adept in specialized laboratory processes and observations, but not in the very general abstractions required by Whitehead. Furthermore, Whitehead's preoccupation with uncovering underlying "truths, involved in the meaning of every particular notion respecting the actions of things" (*PR*, 17 [25]) is not shared by many biologists who seek to solve particular problems. Such divergent cultures with different objectives apparently repel each other and make incompatible bedfellows.

3.2. Possible Solutions to Biological Problems

However, there are biological problems which have not been addressed by mainstream biology but to which Whiteheadian process thought may supply possible solutions. These are: (1) goal-directed activity in organisms; (2) creative adaptation; (3) the composition and unification of wholes from parts; and finally (4) the relation of mind and matter. These questions lie very much at the heart of biology—the study of what life is—yet they are ignored by mainstream biological research.

We will take up each of these problems in turn. First, with regard to goal-directed behavior in biological systems, it is clear that biological systems adopt means to achieve ends. A paradise bird will perform an elaborate courtship ritual to win a mate; a football player will perform sensorimotor control to score a goal; a bacterium will move to find food. Means to ends is teleological action. In Whiteheadian terms, such actions are referred to as immanent, immediate teleologies expressed in the existence of every actual occasion (*PR* 214 [327]).

Second, creativity, particularly in adaptive action to acquire ends, is considered by Whitehead to be a fundamental aspect of organic existence. Adaptive response, creativity, and by extension, evolution are observable features of the natural world. In biology these features are explained away—by means of statistical probabilities in complex information processing in the case of adaptive and creative behaviors in individuals, or by simple statistical probabilities in the case of evolutionary change through mutation and preservation of chance variations. The philosophy of organism, on the other hand, places these features at the very heart of what-there-is.

Third, the unification of parts to form new wholes that give rise to "emergent" properties is returning as a question of interest in systems biology. For Whitehead, these emergent features of nature are not considered as secondary, merely arising from primary physical laws, but are themselves primary "laws," and so Whitehead prescribes to them his "Category of the Ultimate" (*PR* 21 [31]). In other words, the features of existence that we recognize in our lives as being a part of our experience and activity in life, the experiential features that are part of our *mind*, are considered by Whitehead to be fundamental to existence *per se*. The way in which these features are expressed manifests in different physical forms across many spatiotemporal scales; these are the things we recognize as "organisms." Thus, parts form wholes and wholes are parts in larger wholes. Whole "organisms" experience and act with a degree of unity, and therefore a degree of unity of experience and of self-determination. "The many become one and are increased by one" (*PR* 21 [31]).

Finally, we must note the quantum chemical lynchpin that underlies all living things, indeed all non-living chemistry too. The quantum chemical lynchpin is the most basic foundation for any biological system: all biological systems are powered, and their activities directed through biochemical reactions (cf. transformations) that proceed by quantum events. Mechanical events exist at a larger spatiotemporal level, events that are themselves "determined" by quantum ones.

The structure and function of all organisms is dependent on these of quantum "laws" and therefore quantum laws underpin Newtonian mechanics. The question for biology rests very much on whether or not these cumulative quantum interactions between and within molecules have any relevance for the form and function of a cell or multicellular organism. Some might say they do, that they are fundamental to its structure and activity. Others might say they do not, that they are just the peculiarities of an atomic world.

A Whiteheadian conception of organism can be seen as harmonizing successfully with quantum laws, where an approach based on a mechanistic determinism simply cannot.[5] In particular, Whitehead's "occasions of experience" have been argued to be related to quantum events,[6] which would bring our philosophical understanding of nature in line with data from modern physics. While a level of explanation of biological systems at the quantum level may seem remote and distant to the practical problems of biology, we must consider that our system of understanding of life must include all scientific laws and all available data on life, regardless of cultural taboo or current trends in R.A.E.-compatibility. Quantum events, mind and matter, wholes from parts, creativity, and goal-directed activity are all valid, verifiable features of life on which a wealth of data is available to be considered and discussed.

A recent resurgence in Systems Biology is a welcome attempt to reintegrate the disparate fractions of data acquired by the reductionist project of the twentieth century. Systems biology is rapidly coming into vogue as the shining new field in the biological sciences, spurred on by a post-genomic effort to understand integrated biological systems.[7] However, no philosophical re-interpretation of the mechanistic paradigm appears forthcoming, leaving the reintegration of data to be tied together bit by bit, a technique embedded in a reductive, deterministic world-view. It would be interesting to see if Whitehead's philosophy of organism could lend a hand here with some novel and more complete conceptions of whole systems biology.

4. Whiteheadian Biologists

Whitehead's influence in biology is limited and has not shifted the dominant view that an understanding of the organism can be achieved by an understanding of the physical properties of its constituent parts. However, in the early twentieth century Whitehead's work was noticed by a small and important cluster of biologists centered in London and Cambridge. These two cities produced two streams of biological research that were based on, or had been influenced by Whitehead's developing metaphysics of organism; and in turn, Whitehead's metaphysics was probably influenced by them.

First, Joseph Woodger at the University of London was a principal character in extending Whitehead's philosophy into biological thought. Woodger's career is marked by his extensive contribution to studies on biological form and function, and especially on their hierarchical arrangement.[8] His seminal text, *Biological Principles*,[9] expounded a Whiteheadian organicism, emphasizing that parts are only what they are because of, and can only be understood in terms of, their contribution to the whole. Moreover, he emphasized an existentialism of the parts that equates with Whitehead's general notion of pan-experientialism. Woodger attempted to provide biology with a logical foundation on which observations, theories, and methods could be based. He classified the components of an organism on a scale of increasing size and complexity, molecular, macromolecular, cell components, cells, tissues, organs, and organ systems, and noted that each class exhibits new modes of behavior, which cannot be interpreted as being merely additive phenomena from the previous class.

Woodger's thinking about biological principles influenced two young colleagues in Cambridge, both of whom went on to become eminent developmental biologists. On the one hand there was Joseph Needham, a charismatic scientist who would later bridge Chinese and Western science,[10] and on the other there was Conrad Hal Waddington, perhaps the most influential figure from the Whiteheadian school of thought in modern biology, and an avid Whiteheadian scholar. Interestingly, these three biologists were closely related to Whitehead spatiotemporally. They formed, may we venture, a *nexus* of thought.

Waddington and Needham began work on issues of embryogenesis in Hopkins' Laboratory of Biochemistry at Cambridge around 1928, a cornerstone laboratory in the field of biochemistry historically famous for its creativity, breadth and depth of research into the molecular basis of life.[11] Hopkins was particularly encouraging of individual creativity and welcomed Waddington's enthusiasm to study the biochemistry of embryogenesis, a field not yet opened for research. Together, Needham and Waddington worked on the question: how does a single cell, a perfectly round fertilized ovum, develop into an intricate system of many different cell types, organized in predictable patterns, to form a particular kind of living animal? Their research lead to the discovery of signaling centers, areas of the embryo specifically invisible to the eye, but containing within them the potential to induce other tissues to differentiate into patterned structures.[12]

The presence of "evocator" and "reactive" tissue is now a cornerstone of developmental biology and has since been worked up to further demonstrate the importance of reciprocal relations between parts. Evocator tissues are now known as signaling centers, areas with distinct gene expression yet often no morphological difference with surrounding tissue. Signaling centers influences reactive tissue through the effects of diffusible molecules, and conversely reactive tissue often reciprocally evokes evocator tissue. For example, *in utero* in the developing limb, two mutually-dependent signaling centers exist that work to pattern the bones and muscles that give rise to its patterned morphology. When one signaling center is experimentally removed, the other ceases to function and normal growth ceases. Likewise when the other is removed the other ceases to function and normal growth ceases.[13] Their relations form each other and with "creative" advance through time both develop new characteristics enabling them to "experience" their world in a more advanced, novel way. Reciprocating relations through time is essential to the process of creative advance in life and is a feature that can be observed on any level of organization, from the early subcellular interactions of the sperm and the egg, through development of the organism, to the reciprocal and mutually-dependent interactions of organisms in ecosystems.[14]

Waddington was an early scholar of Whitehead and it was this interest that led him to pursue embryology. It was Whitehead "to whose writings [he] paid much more attention […] than [he] did to the textbooks in subjects on which [he] was going to take [his] exams" (Waddington

1975, 3). This early interest remained with him throughout his life and helped to form his orientation. In his autobiography he makes it clear that "the whole of science was dominated by essentially Newtonian conceptions of billiard-ball atoms existing as durationless instants in an otherwise empty three-dimensional space. It was […] Whitehead who suggested new lines of thought" (Waddington 1975, 4). In the 1930's, Waddington established the informal Theoretical Biology Club, among whose interdisciplinary membership included Woodger and Needham, and whose principle position was an exploration of an "organic," or Whiteheadian understanding of biology.

The line of thought initiated by this group was carried forward largely, but dissipated into the middle of the twentieth century under the strain of the success of the reductionist project; even Waddington wavered in his commitment to Whiteheadian ideas.[15] However, a new understanding of organisms and environment took hold in peripheral subject areas, notably in the new fields of ecology and ethology, while ideas of organicism in mainstream biology continued, though in a more subterranean vein—no longer did it hold a principle position among rising stars in Cambridge.

Today, Whiteheadian thinking in biology remains present in a stream of quiet, dissociated research by modern, and often marginalized thinkers such as Erwin Laszlo, Mae Wan Ho, Francisco Varela (in cognitive psychology), and others workers such as the Portuguese biologist José Anunes Serra and the Australian bio-theologian Charles Birch. Additionally, a small number of junior biologists are turning to Whitehead for theoretical and philosophical grounding in an attempt to understand apparent features such as purpose, co-operativity, and creativity in biological systems, of which I would consider myself one. Most recently and by far the most interesting advance in Whiteheadian biological thinking comes from the new Process Philosophy of Chemistry. Here the principal exponents are Jerry Chandler, Joseph Earley, and Ross Stein, all of whom are working to advance our understanding of the nature of atoms and molecules, and the processes of (bio)chemical transformations that they undergo. Chemistry underpins biology and much of biological research today is molecular in nature, examining the chemical process of cell function in its wide variety of forms and functions. A non-reductionist, process-led understanding of chemistry together with a better understanding of quantum chemistry is building a foundation for a useful Whiteheadian paradigm in modern biology.

Erwin Laszlo is one of the most broad and extensive thinkers who firmly grounded his initial work in biological data. He produced a rare and interesting synthesis of empirical data with Whiteheadian process metaphysics, his generalized "Systems Philosophy."[16] This work is essential grounding for any biological thinker. Laszlo combined pioneering ideas in systems theory and cybernetics—work that studied relations between parts to obtain goals, namely that of Woodger and Bertalannfy—with Whitehead's philosophy of organism to advance a general organic biology. This work from the 1970's produced a rigorous theoretical structure grounded firmly in empirical data. He drew on features of nested relationships, systems energetics, and organic hierarchical organization to develop a framework for biological organization and activity. Unfortunately, Laszlo's Systems Philosophy, like Lovelock's Gaia Theory, was not generally accepted by mainstream academic thought, but remains today on the periphery as an interesting and insightful synthesis.

Despite the difficulties of considering organicism in this culture, a modern biologist Mae Wan Ho (1998) recently devised an insightful and plausible hypothesis of organism in line with Whitehead's metaphysics and taking into account Laszlo's work. She further incorporated recent data from cell biology, including her own novel observations on phase shift in cells. Together, she worked to produce a hypothesis of "coherence" in the molecules of a cell or group of cells based on their quantum "alignment." This hypothesis has not been tested.

The connection between mind and body is a difficult one to reconcile in biology. Francesco Varela has worked to bridge cognitive neuroscience with the biological material of the body, and thus to bring notions of mind into the material that "gives rise" to it. Though he rarely referenced Whitehead directly, a distinct Whiteheadian flavor can be found in his writings and research in his emphasis on "embodiment."[17] He brings returns an abstracted and overly intellectual notion of mind from cognitive neuroscience back into the material of the body.

Wilfred Agar worked in Australia in the early twentieth Century, like his British contemporaries, to forward an organic, Whiteheadian understanding of life within the context of biological thinking.[18] His text, *A Contribution to the Theory of the Living Organism* (1943) is a thorough-going synthesis of the philosophy of organism in light of biological data, with emphasis on the qualities and characteristics that make up the organism. His colleague, Charles Birch, has further extended this thinking to take into account the ethical considerations that such a position brings (1999). Birch adds a spiritual, or religious dimension that other Whiteheadian biologists tend to eschew.

Taken together, Whiteheadian thinking in biology is clearly marginal, yet it remains an attractive and potentially useful system of understanding for questions still to be addressed within the domain of the biological sciences.

5. Prospects for Whiteheadian Thought in Biology

The old rift between mechanism and forms of subjectivism (*e.g.* vitalism and organicism) is still alive today, though the mechanistic position clearly dominates the academic landscape, commanding an overwhelming majority of the research money and therefore scientific and social influence. It is clear that mechanism yields results of pragmatic material benefit, while also subjectivism yields results of sympathetic, cultural human importance. For example, in the field of psychosomatic medicine there are clearly biological mechanisms at work behind some symptomologies, but behind others lie psychosocial conditions. The interplay between biological mechanism and psychological condition is an indistinct, yet a vitally important one.

The strength of science is scientific methodology. The success of biomedicine, based on a mechanistic determinism, acts as a bulwark against alternative interpretations of nature. However, there is no reason why alternative philosophical positions, such as Whitehead's, cannot work with the scientific method. It is the scientific method that is important, not necessarily material determinism. One must disentangle determinism from science; the two are too closely associated. *Science is the application of the scientific method. Philosophy is a general systematization of thought* (*PR*, 17 [25-26]).

The scientific method is straightforward and uncontroversial. Each piece of acquired scientific data stands alone as a "truth." Once verified, these truths form a solid basis on which to form opinions, ideas, and hypotheses for other potentially useful truths. Scientific advance works marvelously in this way, each dataset working as a stepping-stone in a world of uncertainty. Importantly, the data itself always remains untainted by philosophical considerations. It is simply what it is. However, the way in which data is interpreted *is* subject to philosophical position. Waddington remarks: "I do not see that [my metaphysical beliefs] have had any direct influence on the way in which I have conducted experimental work […]" (1975, 5). Yet, Waddington adds, "I should like to argue that a scientist's metaphysical beliefs are not mere epiphenomena, but have a definite and ascertainable influence on the work he produces […]" (1975, 1). The scientific work remains the business of science, but the scientist's philosophical position influences the direction that that work takes. Science and philosophy mingle, one step at a time. The data themselves remain untainted by the philosophical position, but the way in which the data are interpreted are subject to influence by philosophy. A stepping-stone process forms where the data remain solid, verifiable phenomena and the interpretive and subsequent planning phases are influenced by philosophy.

One reason that material determinism is so successful is perhaps circular—the underpinning mechanistic philosophy drives the research to look for mechanisms, and when they are found, verifies the assumption. Likewise, a process metaphysic-led research programme could take off in a new direction, also forming its own tautology. In this way, the stepping-stones of testable biological data can be used by any party, or any philosophical position, but the direction that one takes from each stepping-stone to the next is wholly determined by one's philosophical position. The direction dictates the appearance of the next stepping-stone and the direction is philosophically oriented. Process thought can potentially contribute equally as well to the direction of scientific advance as material determinism; its success will depend on the critical and rigorous application of the scientific method to genuinely interesting and useful questions.

6. Concluding Remarks

Whitehead's cosmology makes sense of the bifurcated nature of existence, the private experiential and the public objective aspects. "The distinction between publicity and privacy is a distinction of reason, and is not a distinction between mutually exclusive concrete facts" (*PR* 290 [444]). In his efforts to form a more complete doctrine of what the world is made of, "the theory of prehensions [was] founded upon the doctrine that there are no concrete facts which are merely public, or merely private." Biologists know this to be true through increasing dissections upon dissections of an organism. To discover the private aspect of an organism, biology penetrates its material to reveal complex mechanisms of material action in anatomy, physiology, cell biology, and biochemistry. However, with each reduction we are again confronted with a private and public entity: in dissection of the human body a heart is revealed, in dissection of the heart chambers are revealed, in dissection of the chambers cells are revealed, in dissection of the cells cell organelles are revealed, in dissection of the organelles macromolecules are revealed, and so on until we examine the world of the individual atoms, subatomic particles, the particles of those particles. There is no end to the dissection that science is aware of; always there is a public and private aspect.

Whitehead would have us restructure our conception of how nature is organized to consider both the private and public aspects equally. In his view reality can be analyzed according to "genetic division" and "coordinate division," where the genetic division refers to the character of an actual occasion in "concrescent immediacy," and coordinate division refers to its character as a "concrete object." The two sides of reality, genetic and coordinate, reflect the private and public duality of existence, respectively; they are combined them into one and the same unit, the actual occasion. Each occasion breathes in an inspiration of "feeling" during its genetic, dative phase and exhales during its coordinate, objectification phase to reach what Whitehead calls "satisfaction." In this inward prehension of data and outward expression into objectification, the entity comes into existence in a process comparable to the common, biological process of a living organism.

Whitehead's understanding of life has contributed key concepts to biology for a more fundamental understanding of biological form as it occurs in *living actuality*. He heavily emphasized the importance of time in existence, and therefore the nature of process to all things: nothing is alive without time. His further puts emphasis on feeling as fundamental to process, and the concrete notion of a private and public aspect to all things points toward an understanding of biological systems as *perceptive*, *active*, and *self-determining*. Whitehead's writing can inspire and clearly reminds us that perhaps we are missing "something more" of what we know life is, especially as we become engrained in an industry viewing life merely as a form of reactive biochemical mechanism. "The facts of nature are the actualities; and the facts into which the actualities are divisible are their prehensions, with their public origins, their private forms, and their private aims" (*PR* 290 [444]).

Notes

[1] The term "biology" is taken from *bios* and *logos*, the Greek for "life" and "reasoned account," respectively.

[2] In this chapter, I refer specifically to mainstream, research-based biology that is taught and practiced in the major universities and research institutions. I do this because it is this body of knowledge that is the authoritative form and the one that directly informs the public.

[3] For a good summary see Schrödinger's classic, *What is Life?* (1944).

[4] See especially Agar 1943; for a summary see Agar, 1936.

[5] See Epperson 2004.

[6] See Hameroff 2001.

[7] Systems Biology institutes are being presently being established in most major universities, spearheaded in 2000 by the independent Systems Biology Institute in Seattle and followed closely by institutes at Harvard, Tokyo, St. Petersburg, Ottawa, and others. In the U.K., Systems Biology Institutes have been established at six major universities in the past two years in a concerted national drive in this new, but old direction. Interestingly, the one at Edinburgh will be housed in the C. H. Waddington Building (see below for more on Waddington).

[8] For a brief biography, see Popper 1981.

[9] See Woodger, 1929.

[10] It was no mere coincidence that Needham wrote extensively on both Chinese and Whiteheadian thinking, as they are closely aligned. On Chinese science and culture see especially Needham 1954.

[11] Many eminent biologists passed through Hopkins' laboratory during Waddington's time there; a notable resident was D'Arcy Wentworth Thompson, author of the seminal text, *On Growth and Form* (1917).

[12] For example see Waddington, Needham and Needham 1933.

[13] These reciprocal signaling centers are the Apical Ectodermal Ridge (AER) and the Progress Zone (PZ). The original experiments were performed using micro-dissection: see Harris 1918. It is now know that two genes coding for two growth factors are primarily responsible for this effect, FGF8 from the AER and FGF10 from the PZ, see Ohuchi *et al.* 1997.

[14] For a good overview of these ideas in the context of a developing human embryo and child, see Trevarthen *et al.*, 2006.

[15] See Kenny, Waddington, Longuet-Higgins, and Lucas 1972.

[16] See Laszlo 1972.

[17] For example, see Varela *et al.*, 1991; cf. Stein and Varela, 2000.

[18] See especially, Agar 1936.

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