Living Science:
Science as an Activity of Living Beings

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Abstract

The philosophy of science should accommodate itself to the facts of human existence, using all aspects of human experience to adapt more effectively, as individuals, species, and global ecosystem. This has several implications: (1) Our nature as sentient beings interacting with other sentient beings requires the use of phenomenological methods to investigate consciousness. (2) Our embodied, situated, purposeful physical interactions with the world are the foundation of scientific understanding. (3) Aristotle's four causes are essential for understanding living systems and, in particular, the final cause aids understanding the role of humankind, and especially science, in the global ecosystem. (4) In order to fulfill this role well, scientists need to employ the full panoply of human faculties. These include the consciousness faculties (thinking, sensation, feeling, intuition), and therefore, as advocated by many famous scientists, we should cultivate our aesthetic sense, emotions, imagination, and intuition. Our unconscious faculties include archetypal structures common to all humans, which can guide scientific discovery. By striving to engage the whole of human nature, science will fulfill better its function for humans and the global ecosystem.

Keywords

Philosophy of science, Phenomenology, Embodied cognition, Causality, Analytical psychology

1. Introduction

My topic is an approach to the life sciences, and to science in general, that is grounded in the fact that humans are living beings interacting with each other and with the global ecosystem of which we are part. From this perspective, science is an important behavior by which humankind adapts as a part of the larger ecosystem. Moreover, since human survival depends on earth's ecosystem, I argue that the principal goal of science should be the adaptation and flourishing of the global ecosystem. In other words, humans and our science should be one of the "organs" by which nature adapts and evolves. I call this approach "living science" because it is grounded in the fact that we are living beings interacting as parts of a living ecosystem, which should define the primary purpose and method of science.

In his creation myth in the *Timaeus* (30d), Plato says that

> the god, wishing to make this world most nearly like that intelligible thing which is best and in every way complete, fashioned it as a single visible living creature containing within itself all living things whose nature is of the same order. (tr. Cornford)

In contemporary scientific terms, this is the Gaia hypothesis (Lovelock and Margulis, 1974). That is, the earth's ecosystem is a complex living system — self-sustaining and self-regulating — of mutually interdependent living parts, in which the life of the whole comprises the lives of its parts, and the lives of its parts depend on the life of the whole. Science can contribute to this self-sustaining, self-regulating process.

Since I will argue how science *ought* to be conducted, it is necessary to begin with a prescriptive premise, which I take to be uncontroversial: that humankind *ought* to survive. Therefore, since humans depend on the global ecosystem for our survival, we should understand our scientific enterprise in terms of what it contributes to the flourishing of the whole.

In the remainder of this paper I will explain some of the implications of this approach for science. In the next section I call attention to some obvious characteristics of humankind that, if taken seriously, have implications for the way we do science. They are developed in the remaining sections and include increased use of phenomenological methods, recognition of the role of situated embodiment in cognition, expanded notions of causality, and cultivation of aesthetics, emotion, intuition, imagination, and the unconscious faculties.

2. Science as a Human Activity

Since science is a human activity, it must accommodate the characteristics of humans as they are, not as idealized epistemic agents. I will review several that are especially relevant to living science.

First is the obvious fact that humans are living beings, which brings with it a set of special concerns, such as securing the necessities of life, including food, shelter, and health. Further, living beings are mortal, which implies that to preserve humankind, we must promote the continuation of life beyond our individual lives. The maintenance of life requires a healthy ecosystem, which unites our concerns with the concerns of the larger living world. Therefore, we must also consider human acquisition of knowledge and understanding as a function supporting the global ecosystem, for humans are unique among living things in their ability to adapt and to transform the environment (for good or ill). That is, we must understand science as an activity peculiar to *Homo sapiens* in its role as one of the "organs" (organized functional subsystems) by which the global ecosystem adapts and evolves. Thus science serves as an adaptive mechanism, which can enhance the survival and flourishing of humankind in the larger ecosystem, but also enhance the survival and flourishing of the global ecosystem itself. (Of course, science can serve other ends as well, such as satisfying intellectual curiosity.)

All humans — indeed, all living things — are purposeful. This is not meant to claim that humans and other animals do not sometimes act aimlessly or refrain from acting at all; it does not imply that we never contemplate in a disinterested way. Rather, it is meant to call attention to the fact that living things must act in order to survive as individuals, to promote the survival of their species, or to promote the health of the larger ecosystem on which they depend. Their behavior is directed toward *ends* (goals). (Biologists are rightfully wary of "purpose" and prefer the vocabulary of "adaptation," a topic considered in more detail below: "Four Whys") Therefore we must consider the scientific enterprise in the context of the functions it serves.

Because humans are purposeful, human cognition is fundamentally *situated*, that is, it arises in particular situations (social, cultural, physical) and is applied in particular situations (Brown et al., 1989). Indeed, all animals need to use their knowledge, skills, and understanding in the context of specific situations in order to survive. In contrast, general knowledge, which is abstracted from situations and independent of any context, is harder to acquire and less immediately useful. Traditionally, science has privileged unsituated knowledge, but the reality of human cognition is that it is primarily situated, and denying this reality leads to unconscious biases (e.g., mistaking tacit interest for the absence of interest).

As Aristotle famously wrote, "the human is by nature a social animal" (*ho anthrôpos phusei politikon zôon*, *Pol*. I.1.9, 1253a.). Evolutionary psychologists likewise have concluded that social behavior is characteristic of *Homo sapiens*. Many of our activities are group activities and serve some collective purpose. This is especially true of science, which seeks public knowledge that is equally valid for all people. Moreover, culture is fundamental to human nature. Our social behavior and interactions with the larger world are conditioned by the culture in which we have been born and have grown up. Although we can adapt to other cultures, some of our fundamental psychological structures result from early enculturation and affect our scientific interaction with the world. Moreover science itself is a culture, which overlays our native cultures. Therefore we should not ignore the cultural context of science, or pretend it doesn't exist.

Human beings are sentient, by which I mean that they are sensitive to their environments, bodies, and interior states, and that they consciously experience this sensitivity. This is obvious, but sometimes forgotten when we focus on the objective, empirical, and public character of science. Conscious experience is fundamental to science as a human activity, for all observation is ultimately observation by a sentient being. (Recall that "empirical" derives from Greek *empeiria*, experience.) Therefore, the investigation of conscious experience is fundamental to science; it cannot be ignored or considered beyond the scientific pale. Rather, the scientific enterprise must be expanded to embrace the study of consciousness (see "Three Perspectives" below).

The following sections will explore some of the implications of these human characteristics on the concept and conduct of science.

3. Three Perspectives

Remaining true to human existence requires science to integrate three perspectives, sometimes called first-, second-, and third-person, by analogy with grammar. The traditional perspective of science is *third-person*; that is, it talks *about* the subject of investigation. Science generally treats its subject matter as objects externally related to each other. That is, scientific facts are expressed as properties and relationships that are publicly visible (observable, experienceable) from outside of the objects themselves. Even when we look (spatially) inside an object, it is to observe the relations among the objects inside of it, that is, relations external to the sub-objects.

The usual third-person perspective is too limited when trying to understand conscious experience, which is fundamental to human nature. (I am referring here to *phenomenal consciousness* — our experience of subjective awareness — not to the epistemologically less problematic notion of *functional* or *access consciousness* (Block, 1995).) Science has neglected the investigation of consciousness due to the difficulty of making publicly verifiable observations of conscious experience, which seems to be private. Nevertheless, without a scientific theory of consciousness and how it relates to the physical world, our understanding of existence is radically incomplete. This is the "hard problem" of consciousness (Chalmers, 1995). Consciousness is not simply one of the many phenomena still inadequately explained by science; rather, it is *the* fundamental phenomenon, the precondition for any human observation.

Because conscious experience is private, the experimenter must take an interior perspective, experiencing relationships in which the observing subject is one of the objects related. Whereas the third-person perspective talks *about* the subject of investigation, the first-person perspective talks *as* the subject. Nevertheless, the goal of science is to discover public truths, and introspection is notoriously unreliable. Therefore we need to use reliable means of interior experimentation in order to reach publicly valid conclusions. The fundamental method is *phenomenology*, which may be defined broadly as the investigation of the universal structure (Grk., *logos*) of conscious experience, for a phenomenon (Grk., *phainomenon*) is anything that appears (Grk., *phainomai*) in consciousness.[1]

For example, some forms of *experimental phenomenology* investigate the structure of conscious experience by systematic variation of stimuli and mental intent, and by careful (interior) observation of their effects in awareness (Albertazzi, 2013; Ihde, 2012; Roth, 2012). More generally, phenomenological psychology provides a methodology for producing reproducible observations of conscious experience (Husserl, 1977; Langdridge, 2007; McCall, 1983; Spinelli, 2005). As in any science, reliable phenomenological experimentation requires training in a community of practice so that it will lead to a public body of knowledge.

[1] I use the term "phenomenology" to refer broadly to the Husserl — Heidegger — Merleau-Ponty philosophical spectrum, which have in common the primacy accorded the first-person perspective and a recognition that people are sentient, embodied, situated, purposeful living beings. All these philosophical schools provide methods that may be applied fruitfully, I believe, in living science, for which purpose the differences are less important. A detailed analysis of phenomenological methods is beyond the scope of this paper.

Experimental phenomenology on its own is not sufficient to solve the hard problem, which arises from the problematic relation of conscious phenomena to physical processes (Chalmers, 1995; MacLennan, 1995). In particular, it is essential to understand how phenomenal consciousness is related to processes in the brain. To address this problem *neurophenomenology* combines the first-person methods of phenomenology with the third-person perspective of neuroscience (Laughlin et al., 1990). I have argued elsewhere that we can make progress on the hard problem by parallel reductions in the phenomenological and neurological domains (i.e., parallel first- and third-person reductions) in order to elucidate the structure of consciousness and its constituent qualia (MacLennan, 1995, 1996). Such investigations may reveal how individual neurons contribute to conscious experience and how their interconnections contribute to the topological structure of qualia.

The grammatical analogy to first- and third-person perspectives in science naturally leads us to ask if there is a second-person perspective, and indeed there is. The first-person perspective treats phenomena in a *personal* way, that is, from the interior of the object of study (the sentient experimenter). The more common third-person perspective treats phenomena in an *impersonal* way, that is, as objects without an interior, without sentience. A second-person perspective then treats phenomena in an *interpersonal* way, that is, from the perspective of a sentient experimenter interacting with other sentient beings, in which the objects of study are acknowledged to have inner experiences of their own. In other words, the third-person perspective talks *about* the subject of investigation, the first-person talks *as* the subject, but the second person talks *with* the subject.

Humans are social animals, and this fact is fundamental to human existence and should be to science. For example, in the second-person perspective, people may compare their first-person experiences (for example, suggesting phenomenological experiments and comparing their results), and in this way convert private understanding into the public knowledge that is science. Phenomenological psychology often takes a second-person perspective, in that it involves an investigator interviewing a subject about their interior state. The second-person perspective is also essential to understanding transference and countertransference and similar phenomena in psychology (Perry, 1997).

The second-person perspective contracts the scope of scientific investigation in some ways, but expands it in others. The contraction is most apparent in human-subjects research, for we place ethical limits on research in order to avoid undue pain and distress for research subjects, to protect their autonomy and ability to make informed decisions, to promote their welfare, and to preserve trust between scientists and society at large (e.g., Nat'l Comm. Prot. Human Subj., 1978). Similar limitations apply to animal research to the extent that we judge a species to be sentient. However, with our limited understanding of neurophenomenology, it is difficult to determine degrees of sentience. Historically, some scientists have discounted animals' capacity to feel pain and to suffer in other ways (Easlea, 1980, p. 144), but evidence continues to accumulate that animals have richer mental lives than many people have acknowledged (e.g., Bekoff, 2007). Indeed, I believe that each living thing has a dignity, which we should acknowledge and consider in our scientific investigations.

On the other hand, the second-person perspective expands the scope of investigation in other ways, for it addresses relationships between sentient beings. Humans have sensitive and subtle means for assessing the thoughts, feelings, and intentions of other humans. For example, we can detect subtle differences between genuine and fake smiles (Ekman et al., 1988). We have mirror neurons, which allow us, to some degree, to experience in our own minds the interior states of others (Rizzolatti and Craighero, 2004; Rizzolatti et al., 1996). Therefore, with proper training, humans can become especially sensitive instruments for observing and understanding other humans. For example, we often have a deep (but sometimes inexpressible) understanding of our loved ones. The empathetic understanding possible between people extends as well to other animals. Although we may be separated by our differing species (as humans may be separated by their cultures), nevertheless a deep empathetic understanding is possible between humans and non-human animals.

In summary, since living science is an activity of sentient beings that investigates objects that may themselves be sentient, it must accommodate three sorts of relationships: between objects externally related (third-person), between subjects internally related (second-person), and between the interior of one object and the exterior of others (first-person). All three perspectives contribute to scientific understanding and make it a more effective means to support the global ecosystem and all its life forms, but the first- and second-person research will require the further development of phenomenological methods.

4. Embodied Cognition

Obviously, human beings are embodied, but cognition is often viewed as an abstract process, and scientists as disembodied observers. Recognizing that we are not such should influence the way we understand and do science. Therefore, living science uses the theory of *embodied cognition* to contextualize and broaden the range of scientific experimentation (Johnson and Rohrer, 2007; Varela et al., 1991; Wilson, 2002). Three aspects of human embodiment are especially relevant to living science.

4.1. Active Perception

First, perception is active. Animals do not, in general, passively observe their environments. They explore. They look and sniff around, they taste, they touch and handle, they direct their attention (Gibson, 1979). Moreover, as Mickunas (1974) remarked, “kinaesthetic awareness constitutes our basic ‘perceptual organ’ of space and time,” for by moving in its environment an animal discovers invariants and regularities of change, which are the basis for understanding physical objects and their relationships. In particular, movement and contact generate correlated activity within and between sensory modalities, which provides a basis for discovering the structure of the external world (O’Regan and Noe, 2001). Nervous systems are wired to extract these dynamical patterns and to construct ad hoc neural models of the world. This embodied understanding of our physical environment provides a foundation for our more abstract concepts and thought processes (Lakoff and Johnson, 1999).

Animals interact with the world and adapt to differences between expected and actual outcomes of these interactions. For example, a better than expected outcome causes a dopamine surge, which helps the animal to learn the rewarded behavior, and in contrast a worse than expected outcome leads to a dopamine dip, and therefore a lowered future expectation. Over time, the animal learns to predict rewards and punishments more accurately, and therefore to achieve its ends more reliably. In other ways as well, animals learn from the differences between the expected and actual outcomes of their actions and adapt so that their actions better achieve their ends.

In other words, animals are doing tacit science. They perform experiments and learn by comparing hypothesized and actual results. In the process they construct internal models of the world and their environment from the regularities that emerge from these motor-sensory interactions. (I write "motor-sensory" instead of the usual "sensory-motor" to emphasize the primacy of motor behavior in generating sensory input.)

The regularities discovered are in part a function of the physical structure of both the animal's body and its environment. Its body determines the ways it can act in its environment and the sorts of changes it can sense. Therefore it can extract predictable patterns of interaction between its body and environment. These are patterns that have been adaptive in an evolutionary sense (i.e., tending to improve the organism's inclusive fitness) and may be phylogenetic (characteristic of the species), ontogenetic (arising from the individual's development), or learned.

We humans are no different, and human understanding of the world is in part conditioned by the physical structure of the human body. Of course we use tools and instruments to extend the capabilities of the body to act on the world and to perceive the consequences. Therefore it is the artificially augmented body that forms the background of the regularities that we can discover. In this context, it is important to be aware that all tools are *reductive* as well as *ampliative* (Ihde, 1986, pp. 104–136); that is, while augmenting our abilities in some ways, they inevitably decrease them in others, and we need to consider the balance. For example, a stick extends our reach, but has less tactile sensitivity than our hands. The instruments we use condition the reality we discover.

4.2. Experience is Interactive

Phenomenology reveals that experience is fundamentally *interactive*, another aspect of embodiment. That is, humans and other animals act purposefully in their environments with accompanying expectations for the outcomes of those interactions. The notion of a *disinterested observer* is at best an idealization, at worst a fiction by which we deceive ourselves. (Thus "experimenter" — from *experior*, to attempt, test, experience — is a more accurate term than "observer.") Even when we take the third-person perspective, in which the experimenter is not the intended object of observation, the interests and situation of the investigator affect the experiment insofar as they condition the actions taken and the consequences to be observed.

The interests of the experimenter are even more relevant in investigations that require a first- or second-person perspective. In the first case, the actions and experiences of the experimenter are the object of study. In the second case, the experimenter(s) and subject(s) are interacting and producing a joint experience. In neither case can the experimenter be considered aloof from the experiment.

In summary, experience, and the phenomena that constitute experience, are primarily interactive. Therefore, science, in the broad sense, is fundamentally *participatory*, for it is by participating in the world that we come to know it.

4.3. Adaptation

The outcomes that animals actually experience as a result of their actions condition their future actions and expectations, for the differences between the expected and actual outcomes, in the context of their interests and purposes, initiate and guide *adaptation*, a key aspect of human embodied cognition. As previously noted, an outcome that is better than expected — relative to the actor's interests — may result in a dopamine surge, which causes neural systems to adapt to make the preceding action more likely. Conversely, if the outcome is worse than expected, then the dopamine dip causes neural systems to make the preceding action less likely. In both cases neural systems adapt to decrease the divergence between prediction and outcome, so that the animal can anticipate the consequences of its actions more accurately. This example illustrates that adaptation is intimately involved with emotions, values, and interests. Values (generally tacit) determine interests, which govern emotions. I will address the role of emotion in living science below ("Integrated Understanding").

At a higher level, an animal's adaptation as a consequence of its interaction with the world provides a model for scientific interaction with the world. We experiment; that is, we interact with the rest of the world with certain expectations for the results of those interactions. And then we adapt, so that the outcomes of future interactions are more predictable. In the process, we are pleased when the outcomes are better than we expected, and disappointed when they are not. There are of course many senses of "better," depending on the values, interests, and situations of the individuals and groups involved. They may be tangible (e.g., economic or otherwise practical) or more ephemeral (e.g., understanding, beauty, awe).

In summary, the foundation of human understanding is embodied interaction with the physical environment, the consequences of which lead to adaptation in accord with our interests. Living science recognizes and takes account of these fundamental characteristics of human understanding in determining the goals and conduct of scientific investigation.

5. The Four Whys

Science seeks explanations in order to predict the outcomes of actions more accurately and to achieve our goals more effectively, because explanations are the principal means of explicitly capturing the regularities of motor-sensory interactions (experiments). In order to understand living systems, in particular, it is often valuable to expand the familiar range of causal explanations to include all of Aristotle's "four causes," since his philosophy of science was biological in focus, and his explanatory framework has continued to be valuable in biology. For example, it was the inspiration for Tinbergen's "four questions" (Tinbergen, 1963), which have organized behavioral investigations in ethology, comparative and evolutionary psychology, anthropology, and behavioral ecology (Hladký and Havlíček, 2013).

First, however, we must be careful not to be misled by conflating the modern physical meaning of "cause" with the Aristotelian concept. The ancient Greek word *aitia* (or *aition*), often translated "cause," primarily means responsibility, blame, or credit for some occurrence (Liddell et al., 1968, s.vv. αἰτία, αἴτιος). In a philosophical context, it is "that because of which" (*to dioti*), "the why"; sometimes it is translated "explanation" (Barnes, 1982, p. 52; Hankinson, 1999, pp. 86, 132; Peters, 1967, s.v. aition; Randall, 1960, pp. 34–35, 123–124).

The importance of the four whys for living science is that our contemporary notion of causation is often inadequate when applied to biological phenomena. Its explanations may be correct, but not very informative. For example, the beating of the heart can be explained in terms of neural impulses and muscular contractions (an explanation in terms of motion), but that leaves out the important fact that its function is to circulate the blood (an explanation in terms of function or purpose). Each of the four explanations elucidates different aspects of the phenomenon, and our understanding is incomplete without them all. For any given biological phenomenon, and in a particular context of inquiry, some of the explanations may be more informative than the others, but they all contribute to our understanding. The modern evolutionary synthesis has not supplanted the Aristotelian taxonomy; rather, "Darwin made it possible to put all four Aristotelian causes into science" (Pigliucci, 2001).

To review, Aristotle distinguishes four sorts of explanations that can arise from why questions, in particular, why any particular biological phenomenon occurs (Aris., *Phys*. II 194b–195a, *Met*. 983a–b, 1013a–1014a).

The first way to explain some thing, or some process in that thing, is by asking, "What is it?" In this case the answer is the thing's *What* (Grk., *to ti esti*). This kind of explanation is known traditionally as the *formal cause* because it is an appeal to "the form [*eidos*] or pattern [*paradeigma*]; that is, the essential formula [*logos*] and the classes that contain it" (Aris., *Met*. 1013a26–28). In other words, it explains the thing by reference to a universal of which it is an instance. For example, we may explain a particular animal's behavior by noting that it is a rat and that such behavior is characteristic of rats. Formal causes include mathematical explanations (formulas) or models, which give the form or pattern of a process independently of the material in which it is instantiated. Explanations of behavior or cognition in terms of information processing and control are also examples of formal causes, because the processes can be explained in terms of formal relationships independent of their material instantiation (MacLennan, 2011). That is, information is represented by distinctions of *form* (organization or arrangement), and information processing proceeds by means of *transformation* (reorganization and rearrangement). The material substrate of the information has less explanatory value.

Mathematics is an essential tool in modern science for expressing formal explanations, but it can be difficult to quantify phenomenological structure. This does not imply, however, that mathematics cannot be applied in first- and second-person investigations, but it does imply that more qualitative mathematical disciplines are more useful. For example, phenomenological experiments may reveal order relations (e.g., total orders, partial orders) and their associated algebraic structures (e.g., lattices). Topology is also useful, since it can deal with issues of connectivity and relative nearness in a non-quantitative way.

The second "why," the *From What* (*to ex hou*), traditionally known as the *material cause*, explains an object in terms of the substance from which it is made and explains a process in terms of the substance or substrate in which the process occurs. In particular, from an Aristotelian perspective form and matter are complementary, since the matter is necessary for the form to be realized and unformed matter is nothing in particular. Sometimes the formal cause has greater explanatory value (e.g., for information processing and computation), and sometimes the material cause is more illuminating (e.g., to explain a neurodegenerative disease or a computer chip that overheats), but both must be present. The material cause of the heart is the various tissues and cells (epithelial, striated muscle, cardiomyocytes, pacemaker, etc.) from which it is made; its formal cause is the structure (layered tissues, chambers, neural networks, etc.) that allows these elements to contract in a coordinated fashion in order to circulate the blood.

Form and matter are also relative terms, because a form may be instantiated in a kind of material, which itself is a form impressed on a different underlying material. For example, cognitive processes may be explained in terms of a formal organization of underlying cortical tissue, but that tissue has in turn its own formal structure imposed on another material (individual neurons), which in turn has a complex structure imposed on proteins and other molecules. Therefore, the notions of form and matter are applied hierarchically, and living systems self-organize, creating higher levels of form (organization) out of lower ones.

A third way to explain a process is in terms of an external agent or mover starting, stopping, or maintaining the process. We may call this the *By What* (Grk., *to hypo tinos*), traditionally known as the *efficient cause*. This explanatory mode is familiar in the common notion of "cause" in contemporary science resulting from the predominance of mechanistic explanations since the seventeenth century. What made the neuron generate an impulse? Sufficient stimulation from other neurons. What made the rat run away? The arrival of the cat.

The fourth sort of answer to a why question, which is of especial relevance to living science, explains a thing or process in terms of its goal or function. This explanation is the *For Sake of What* (*to hou heneka*), the *final cause*, which refers to the end, aim, or purpose of the process (Lat., *finis*). These kinds of explanations are often informative and indeed they are essential in the life sciences, for survival of the individual and of the species requires that many important functions be fulfilled. For biological processes the final cause is often the most important, for the goal can be accomplished in many different ways (i.e., by alternative formal, material, and efficient causes). (This is why, for example, we can have artificial hearts.) The other three causes together may serve as the *means* to accomplish the *end*, which is the final cause.

One of the fundamental characteristics of life is its *teleonomy*, that is, its apparent goal-directedness (Pross, 2012, pp. 9–20); often, the most informative explanation of a biological structure or process is its function, the purpose it serves. Physiological processes and organ systems fulfill various functions *for the sake of* (in the first instance) the survival of the organism, in a broader sense, for the sake of the survival of its group, and in a yet wider sense, for the survival of its species. Transient individual organisms provide for the continuity and evolution of their species (Pross, 2012, pp. 185–186). That is, there is a teleonomic hierarchy in which sub-goals support super-goals. Since species are mutually dependent on each other and on the ecosystem as a whole for their continued evolution and survival, the global ecosystem as a whole constitutes an effective ultimate goal, for the sake of which all life exists.[2] Therefore, the starting point for analysis in terms of final causes is an integrated global ecosystem, which has maintained its dynamic, nonequilibrium state for some billions of years ("Gaia," if you will). This, I think, is the closest thing to absolute teleonomy that we can grasp from science.

Species behave and evolve primarily for their own sakes (qua genomes), but also for the sake of the ecosystem as a means to this end. In this sense, the global ecosystem's constituent evolving species exist *for the sake of* the whole. Metaphorically, they are its organs. Of course, at any given time, some populations may be neutral in their effect or even deleterious (*Homo sapiens*?), just as organs and instincts can become vestigial or maladaptive. The perspective of living science calls attention to the fact that humans are living beings, and therefore that we too exist for the sake of earth's ecosystem, and therefore the ultimate aim of human activities, such as science, should be its continued persistence.

In summary, these four explanations reinforce and complement each other to yield a deeper understanding of a biological phenomenon. They address four complementary kinds of answers to the "Why?" of a biological phenomenon. In living science they apply to the objects of scientific investigation but also to the scientific enterprise.

[2] I don't try to extend this argument beyond the earth for two reasons: (1) extraterrestrial life is yet to be discovered; (2) even if there is extraterrestrial life, our global ecosystem is quite isolated and does not seem to be interdependent with other planetary ecosystems.

6. Integrated Understanding

6.1. Conscious Faculties

We are integrated organisms with many faculties, not merely rational machines. If our goal is to become better adapted through science, then our methods must take account of the whole human being. Of course this includes our conscious rational faculty and the tools that serve it, such as mathematics, but this does not exhaust our conscious faculties. Carl Jung identified four functions of consciousness: sensation, thinking, feeling, and intuition (Jung, CW 6, ¶¶ 7, 983–985). Sensation and thinking, of course, have been fundamental to science. But our emotional and aesthetic responses, which are deep seated and sensitive evaluative organs, are also critical for scientific discovery, as many famous scientists have acknowledged.

For example, in "The meaning of beauty in the exact sciences," Werner Heisenberg asks, "How comes it that with this shining forth of the beautiful into exact science the great connection becomes recognizable, even before it is understood in detail and before it can be rationally demonstrated?" (1974, p. 175). Moreover, "Among all those who have pondered on this question, it seems to have been universally agreed that this immediate recognition is not a consequence of discursive (i.e., rational) thinking" (Heisenberg, 1974, p. 177). Nobel Laureate William Lipscomb's discoveries were confirmed experimentally, "but the processes that I used and the responses that I felt were more like those of an artist" (Curtin, 1982, p. 4). Another Nobel Laureate, Chen Ning Yang, says, "It is astonishing that sometimes if you follow the guidance toward beauty that your instincts provide, you arrive at profound truth, even though contradictory to experiments" (Curtin, 1982, p. 36). He cites P.A.M. Dirac, who was led by beauty to the discovery of antimatter and wrote "it is more important to have beauty in one's equations than to have them fit the experiments" (Curtin, 1982, p. 36).

In the contest of beauty and data, it is often wiser to bet on the former as the more reliable predictor of truth; the data usually conform in the end. Hermann Weyl (half joking) said, "My work always tried to unite the true with the beautiful; but when I had to choose one or the other, I usually chose the beautiful" (Dyson, 1956). Asked for examples, he cited two of his theories that he defended in spite of apparently disconfirming experimental results; both were eventually proved correct (Chandrasekhar, 1987, pp. 65–66).

> We have evidence, then, that a theory developed by a scientist, with an exceptionally well-developed aesthetic sensibility, can turn out to be true even if, at the time of its formulation, it appeared not to be so. As Keats wrote a long time ago, "what the imagination seizes as beauty must be truth — whether it existed before or not." (Chandrasekhar, 1987, p. 66)

Given the importance of aesthetic sensibility and emotion in science, we should inquire into its nature. An emotion may be defined as a state evoked by a reward or punisher, either present or remembered, which results in reinforcement (Rolls, 2007). (The reward or punishment is relative to expectations, as we've seen.) Emotions are goal-oriented, that is, adaptive in the sense of inclusive fitness (Plutchik, 2003, pp. 218–23) and serve several specific functions (Rolls, 2005, 2007). For example, they are immediately motivating and directed toward action, and therefore they can elicit actions that lead to perception. Emotions also establish a persistent psychological state, which biases cognitive processing in relevant ways, thereby helping the brain to extract relevant perceptual invariances and regularities. In particular, emotions provide for behavioral flexibility, since they represent a behavioral situation that can be indicated by a variety of stimuli and responded to in a variety of ways; that is, an emotion represents a behavioral invariant. Emotions facilitate social behavior by means of care, sympathy, and genuine interest. Finally, emotions regulate social interactions, such as cooperation, and facilitate communication of mental state; they provide a basis for empathetic understanding of other animals, especially other people. Therefore emotions are important in second-person experiments, for empathetic reactions provide a kind of direct access to the interior state of the other animals via mirror neurons (Rizzolatti and Craighero, 2004; Rizzolatti et al., 1996).

In first-person experiments, emotions provide a way of observing one's own unconscious and physiological state, which would otherwise be invisible. Like the senses, the emotions are more immediate than reason, which is often left the task of rationalizing emotional judgment. Most contemporary theories of emotion are some variant or extension of the *visceral* or *somatic* theory of emotions, proposed independently by William James (1884) and Carl Lange (1885) (e.g., Damasio, 1994, ch. 7, 1999, ch. 9; Prinz, 2004, pp. 4–5). The primary emotional response is processed by the limbic system (especially the amygdala) and is largely unconscious. The resulting physiological changes are detected by neurons responding to visceral organs, skeletal muscles, hormone levels, etc. These signals are integrated in higher, cortical areas, where the somatic effects are felt and experienced as emotions (Damasio, 1999, pp. 42–9, 60–1). Categorization of the feelings as a particular emotion occurs at a third, higher level of the hierarchy (Damasio, 1999, p. 8; Prinz, 2004, ch. 9). The resulting phenomenology of emotion is complex and incompletely understood; see the discussion and citations in MacLennan (2009).

Our emotions inform us about the world, just as our senses do, and both must be trained in order to make a reliable contribution to scientific understanding. More precisely, as sensory perception is one class of consequences of our interactions with the world, so emotional perception is another class of these consequences; the two extract different sorts of regularities and permit us to make different sorts of predictions. Since emotions are inherently motivating, emotional perception may be more relevant to goals and values. For example, an important dimension in emotional phenomenology is the *valence* of an emotion: whether it is positively or negatively reinforcing, and therefore tends to promote approach or avoidance (Panksepp, 2004, p. 46; Plutchik, 2003, p. 21; Prinz, 2004, pp. 167–78; Rolls, 2007).

Much of our emotional response is learned, and therefore it is important that scientists develop their skill in emotional perception and learn to use it well, just as it is necessary for them to train their observational skills. One way to do this is by developing the aesthetic sensibilities, as many scientists have observed (e.g., Farmelo, 2002). For example, the importance of elegance in mathematics is widely acknowledged, both as guide in research and as a criterion by which results are evaluated (Lang, 1985; Rota, 1997). Likewise, in all the sciences, we should consider aesthetics in design of experiments and in the presentation of results, so that science better serves the adaptive function of the human species (MacLennan, in press).

Summarizing, in nature we know emotions drive adaptive behavior, and in science many of the most famous scientists have stressed the central role of aesthetic considerations in their discoveries. When rational and emotional judgment are united in understanding, we have the deepest sort of comprehension of the world and our place in it. "The measure in which science falls short of art is the measure in which it is incomplete as science" (J.W.N. Sullivan, quoted in Curtin, 1982, p. 8).

The last of Jung's four functions is intuition, which is also essential to science. Albert Einstein wrote, "There is no logical way to the discovery of these elemental laws. There is only the way of intuition, which is helped by a feeling for the order lying behind the appearance" (Beveridge, 1957, p. 57). Also essential to scientific discovery is the imagination, which must be guided by intuition in order to be fruitful. Max Planck said, "imaginative vision and faith in the ultimate success are indispensable. The pure rationalist has no place here" (Beveridge, 1957, p. 55). The creative discoveries of such scientists as Isaac Newton, John Dalton, and Humphry Davy have been credited to their imagination (Beveridge, 1957, p. 58). As will be discussed below, imagination was also fundamental to Goethe's scientific methodology. See additional examples in Root-Bernstein and Root-Bernstein (2003).

Although intuition is a function of the conscious mind, its roots lie deeper, in the unconscious, and "compleat scientists" will also apply their unconscious faculties in their scientific endeavors. What are these faculties?

6.2. Unconscious Faculties

We know from neuropsychology that most of the activity in our brains is unconscious, that is, not directly accessible to conscious introspection. As we've seen, this includes the earlier, lower levels of emotional processing. Much of this response is learned, but we also have innate unconscious psychological structures, which influence all four conscious functions.

Like other animals, humans have evolved behavioral adaptations ("instincts") that regulate our interactions with each other and with the rest of the world. The human genome has not changed substantially since modern humans emerged about two hundred thousand years ago, and for most of that time (until about ten thousand years ago), we have been hunter-gatherers (Wilson, 1978, pp. 87–88; see also Gibbons, 2010). This constitutes our *environment of evolutionary adaptedness* (EEA), the environment in which we have evolved and to which we are adapted. Therefore, our evolved behavioral adaptations can be understood in terms of the functions they served in that environment; this is their final explanation, their *For Sake of What*.

These phylogenetic adaptations have both an exterior aspect, as complex behavioral programs, and an interior aspect, as unconscious psychological structures, which regulate perception, motivation, affect, and behavior in order to fulfill biological ends in our EEA (Sabini, 2000; Stevens, 1993, pp. 63–67). They are formal structures that, when activated, impose themselves on concrete situations (their “matter”). Jung called these innate formal psychological patterns *archetypes* and described them as “active living dispositions, ideas in the Platonic sense” (Jung, CW 8, ¶ 154). They reside in the *collective unconscious*, which is *collective* in that it is phylogenetic, and therefore common to all humans, and *unconscious* in that these psychological structures cannot be observed by introspection, but known only through their indirect effects on conscious experience (Stevens, 2003).

Therefore science, as a means of bringing our understanding into greater conformity with the world in which we participate, must also take account of the archetypal psychological structures that are part of our phylogenetic heritage. These inherited adaptations regulate perception, motivation, affect, and behavior to serve biological ends, and they must be accommodated in any epistemology consistent with biological reality. They are the natural (i.e., phylogenetic) categories of our purposeful, situated interaction with the world, which is the foundation of living science. They are the channels in which our intuition naturally flows.

Heisenberg mentions Johannes Kepler and Wolfgang Pauli as scientists who attributed scientific discovery “to innate archetypes that bring about the recognition of forms” (1974, p. 178–9). For example, Kepler wrote of a “faculty of the soul, which does not engage in conceptual thinking” capable of perceiving *a priori* patterns in the world, for “all pure Ideas, or archetypal patterns of harmony … are inherently present in those who are capable of apprehending them” (Chandrasekhar, 1987, pp. 66–67). And Pauli wrote of

> forms belonging to the unconscious region of the human soul, images of powerful emotional content, which are not thought, but beheld, as it were pictorially. The delight one feels, on becoming aware of a new piece of knowledge, arises from the way such pre-existing images fall into congruence with the behavior of the external objects. (Chandrasekhar, 1987, p. 67)

Therefore, we should teach scientists to be sensitive to manifestations of the archetypes through their effects on perception, emotion, and motivation. By empathetically and imaginatively participating in a natural process under investigation, the intuition is guided to new insights, which can be confirmed by elegant experiments and expressed in beautiful mathematics.

I should mention two early advocates of living science, in the sense described herein. The first is Johann Wolfgang von Goethe, who was an avid scientist, and the second is Ralph Waldo Emerson, whose views on science were strongly influenced by Goethe’s (Obuchowski, 2009).

Goethe’s scientific methodology, which he called a “delicate empiricism” (*zartre Empirie*), has been characterized as empathetic, participatory, and holistic (Bortoft, 1996, pp. 3–26, 49–76, 321–30; Naydler, 1996, pp. 12, 22, 28, 41, 48; Pauli, 1955, pp. 205–6). It involves an imaginative and intuitive participation in the archetypal structure of the phenomenon under investigation, so that by experiencing it in oneself, one can grasp it more intimately. Thus interior and exterior experience are brought into correspondence. Goethe acknowledges “that my thinking is not separate from objects; that the elements of the object, the perceptions of the object, flow into my thinking and are fully permeated by it; that my perception itself is a thinking, and my thinking a perception" (Goethe, 1995, p. 39). Likewise, Emerson said, "The man thinks he can know this or that, by words and writing. It can only be known or done organically. He must plunge into the universe, and live in its forms, — sink to rise." (Emerson, 1909–1914, vol. 8, p. 445)

Emerson also observes, "This is evidently what Goethe aimed to do, in seeking the arch-plant, which being known, would give, not only all actual, but all possible vegetable forms" (1909–1914, vol. 3, p. 295). For by comprehending the arch-plant (*Urpflanze*) in himself and by realizing the generative potential of plants in his own imagination, Goethe understood not only the structure of all existing plants, but the structure of all possible plants. Similarly, by application of his morphological imagination, Goethe realized that humans, like other animals, must have an intermaxillary bone, a fact denied by other naturalists, but which he confirmed (Goethe, 1995, pp. 111–16). This discovery helped establish the evolutionary continuity of humans with other animals.

In an introduction to a selection of Goethe's scientific writings, Jeremy Naydler summarizes the promise of Goethe's method:

> If we allow intuitive thinking, feeling, and imagination a place in our scientific method, then — providing these are deployed in conjunction with exact observation and clear thought, and providing they are trained as thoroughly as our powers of observation and thinking — then a much fuller and more complete experience of nature will become possible. (Naydler, 1996, p. 115)

As Douglas Miller explains, "this inner activity turns into intuitive perception, the bridge between empirical phenomena and the archetype. It requires intense schooling of the perceptive organs and imagination to become a worthy participant in the creative processes of nature" (Goethe, 1995, p. xxi). Progress in science and the self-development of the scientist proceed in tandem:

> Goethe realized that proper scientific work should bring a change in the scientist himself, especially in his mode of perception, and that this change then affected the practice of science. … [H]e demanded that the scientist develop new organs of perception to participate in natural processes actively, objectively, and imaginatively. (Miller in Goethe, 1995, p. xxi)

Full participation in the life of the universe as integrated human beings can benefit the ecosystem, improving its ability to adapt, but also enhance our human lives.

> Indeed, if Goethe's approach extends our modern-day vision of nature to include a greater sense of dignity, respect, and purposefulness, so too may it extend our vision of man. In the words of the physicist Werner Heisenberg, whatever other value we may cull from Goethe's method, "Even today we can still learn from Goethe that we should not let everything else atrophy in favor of the one organ of rational analysis; that it is a matter, rather of seizing upon reality with all the organs that are given to us, and trusting that this reality will then also reflect the essence of things, the 'one, the good, and the true.'" (Seamon, 1978)

To engage in science with the faculties of the whole human being it is necessary to apprehend the archetypes and to integrate them into consciousness. This is a lifelong undertaking, which Jung terms *individuation*, for its goal is to become whole and undivided (Lat., *individuus*) (Jung, CW 9i, ¶ 490). To this end, various practices from analytical psychology, such as *active imagination*, are very helpful (Johnson, 1986; Jung, 1997; MacLennan, in press).

7. Conclusions

Human beings are living things, and like all living things we live in mutual interdependence within the global ecosystem of which we are parts. The philosophy of science, then, must accommodate itself to the facts of our existence, using all aspects of human experience to adapt more effectively, as individuals, species, and global ecosystem. This has several implications. First, our nature as sentient beings interacting with other sentient beings requires that the traditional third-person perspective of science be supplemented by first- and second-person perspectives (intrasubjective and intersubjective phenomenology). Second, we are embodied, and therefore much of our experience is a result of our situated, purposeful physical interaction with the world, including other sentient beings. These physical interactions are the foundation of scientific understanding. Third, in order to understand living systems it is often informative to appeal to Aristotle's "Four Whys," which account for objects and processes in four different ways. In particular, the *For Sake of What* (final cause) is informative for understanding the function of humankind, and especially science, in the global ecosystem, whose thriving stands as an ultimate final cause, at least so far as terrestrial life is concerned. Fourth, in order to fulfill this function well, scientists need to employ the full panoply of human faculties. These include the four functions of consciousness enumerated by Jung (thinking, sensation, feeling, intuition), and therefore, as advocated by many famous scientists, we should cultivate our emotions, aesthetic sensibility, imagination, and intuition. Our unconscious faculties include archetypal structures common to all humans, which can guide scientific discovery. By striving to engage the whole of our human nature in science, we will become better scientists and will create a living science that better serves the living world.

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