Earth System Science and Gaian Science
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Introduction.

Conventional science and technology have provided many benefits, but have also unintentionally contributed to the current ecological and social crises, characterised by the mass extinction of species, climate change and social breakdown. It seems that conventional science has been insensitive to its own ill effects, preferring to believe that it generates 'objective' information about the natural world, which scientists then hand over to society at large to interpret and implement. A hallmark of conventional science is the separation of facts from values. Conventional science thus expunges questions of morality and meaning from its methodology, preferring instead to focus on the acquisition of knowledge for its own sake and for the control of nature for the expansion of human interests, irrespective of the intrinsic value of the natural world. Wildlife and fisheries biology, forestry, recombinant DNA studies linked to GM technology, organic chemistry linked to the use of pesticides, and the science behind the intensification of agriculture all provide telling examples of how the urge to control has had severe negative impacts on nature.

Holistic science is an attempt to move beyond these limitations without losing the many benefits that conventional science has to offer. I propose that two modes or tendencies can be discerned within holistic science, and that an interest common to both modes is the phenomenon of emergence, to be defined below. 'Detached' holistic science studies emergence and whole systems, but agrees with conventional science that value questions are of no concern in science. 'Participatory' holistic science also seeks to understand emergence and the behaviours of whole systems but does not accept the separation of fact from value, realising instead that knowledge and appropriate action must be intimately linked in the practice of science. I suggest that these two modes of holistic science are reflected in two approaches to the scientific understanding of the Earth: Earth System science and Gaian science. These can be distinguished from each other by the former's lack of concern with value questions, and by the latter's concern with bringing intuitions of the intrinsic value of nature right into the heart of scientific practice. However, it should be borne in mind that the dichotomy presented here (between Earth System science and Gaian science) is a charicature or 'cartoon' of the complexities of the real world, in which holisitically inclined scientists move back and forth between the two modes. Thus my dichotomy should only be seen as a heurisitc device for stimulating discussion on the place of values in scientific discourse and practice.

The Scientific Revolution.

We have inherited conventional science from the scientific revolution of the 17th century. Bacon suggested that we must torture nature's secrets from her in order to gain dominion over nature for the benefit of humanity, that we must gain knowledge for control of nature. Galileo stressed the primacy of the quantifiable, affirming that subjective experience can tell us nothing useful about the world. Descartes asserted that the universe, including the human body, is a vast, inert machine, and that the screams of vivisected animals were to be disregarded, since for him they were no more than the creakings of mere mechanisms. Newton's equations appeared to verify this mechanistic world-view, as with their use scientists could accurately predict the movements of projectiles and celestial bodies. Two centuries after Galileo, Laplace went so far as to comment that if it were possible to quantify everything in the Universe at a given moment, then its entire future could be accurately predicted using this new scientific method, including all subsequent human behaviour. This perspective strengthened the belief that the world is machine, having value only when converted by science and technology into objects useful for human purposes.

However, there are other ways of knowing the world. The pre-scientific understanding, eventually pushed underground by the scientific revolution, was that the world was suffused with intelligence, agency and soul, even down to the level of matter. Far from being a machine valued only according to utilitarian criteria, the world was experienced as a living being in its own right, infused with intrinsic value. Like the pre-scientific West, many non-western cultures saw humans as humble strands in the web of life, not as its masters, and revered rocks, trees and rivers for their special, intrinsic qualities. Intuitive modes of knowing about intrinsic values, which conventional science regarded as peripheral, were central to these ways of relating to the world.

From Conventional Science to Holistic Science.

As mentioned above, a key characteristic of holistic science is a focus on the phenomenon of emergence. Conventional science is built on the premise that it is possible to understand the workings of complex systems by studying the properties of their constituent parts. There is no doubt that this 'reductionist' methodology has yielded remarkable insights. However, holistic scientists hold that reductionism is limited, and that it must be complemented with the recognition that complex systems have 'emergent properties' which are influenced but not determined by the properties of their parts. Silberstein (1998), provides a useful definition: 'Emergent properties are qualitatively new properties of systems of wholes that posses causal capacities that are not reducible to any of the causal capacities of the parts'.

Holistic science involves the study of emergent properties across a large range of temporal and spatial scales in a wide variety of situations. Models of social insect colonies yield good examples of emergence. Goodwin and colleagues (see Goodwin 1994) modelled colonies of the ant *Leptothorax*, based on earlier work showing that activity patterns of individual ants either on their own or interacting with others at low density, were chaotic in the technical sense. In the model, individual ants were programmed to become active whenever an internal variable obeying an equation for deterministic chaos exceeded a threshold value. Ants moving over a virtual grid could also activate other ants which were either active or at rest. Colony density was a parameter which was systematically altered. The surprising result was that rhythmical patterns of activity emerged in the colony as a whole at a critical colony density, despite the fact that the underlying activity pattern of every individual ant in the model was chaotic. This rythmicity, which is an emergent property of the colony as a whole, has so far proved impossible to explain using classical reductionist approaches.

Lovelock's Gaia theory provides another striking example of emergence, proposing that self-regulation of key variables for life, such as planetary temperature and atmospheric composition emerge out of tightly coupled feedbacks between life and its non-living environment - the rocks, atmosphere and water (Lovelock 2000). Life and the abiotic environment evolve as a single, life-like entity, Gaia, which is studied as a whole, without losing sight of relationships amongst entities at lower levels in the system.

For holistic science, relationships are primary. Objects can only be understood through their relationships, and indeed are themselves made up of complex networks of internal relations. The world thus consists of nested sets of networks within networks. This point is well illustrated in quantum theory, where there are no billiard ball-like solid particles, but rather wave-like patterns of probabilities of relationship between the 'entities' concerned.

By contrast, conventional science is concerned primarily with describing and understanding the behaviour of objects. In physics, this view gives us the classical understanding of non-living objects as ‘billiard balls’, which behave in predictable ways according to Newton’s equations. In this view, relationships between objects are acknowledged, but are not considered to be of primary importance.

The followers of Descartes and Laplace believed that science could provide total certainty and absolute predictability, but conventional science has recently been forced to admit that such claims are totally unachievable. Chaos theory has shown that even simple non-linear systems are inherently unpredictable, and quantum physics has demonstrated that the behaviour of sub-atomic particles cannot be fully described.

Furthermore, conventional science believes in objective description, in observations and conclusions which are independent of human observers and the methods used to obtain observations. Holistic scientists believe that objective knowledge is impossible to attain, since all knowledge depends on how the scientist has interacted with the natural world, Because of this, the process of acquiring knowledge should be included in scientific descriptions. This insight is exemplified by Werner Heisenberg, one of the great quantum physicists of the early part of the last century, who said that “what we observe is not nature itself, but nature exposed to our method of questioning”. Finally, holistic science has learnt from Thomas Kuhn (1962) that science deals with paradigms - the values, attitudes and techniques underlying scientific descriptions, which change as new views of reality emerge into scientific consciousness.

For more detailed descriptions of the contrasts between conventional and holistic science (which Capra calls 'systems thinking') see Capra (1997) and Capra and Steindl-Rast (1991).

<u>Two modes of holistic science</u>

'Detached’ holistic science (Table 1), is a more ‘holistic’ version of conventional science. It is interested in understanding emergent phenomena, yet it continues to believe in the possibility of detached observation, has implicit instrumental values, tries to gain knowledge for control of nature and hardly acknowledges the value of intuition in scientific discovery. Even though one might be told by its practitioners how certain scientists, such as Kekule and Medeleev received important scientific insights in dreams, detached holistic science offer no systematic methodology for cultivating the intuitive faculty.

Finally, detached holistic science recognises that traditional academic barriers are an impediment to the understanding of emergent phenomena, and seeks to build complex, trans-disciplinary ‘systems’ models which can then be scrutinised and tested from the ‘outside’.

The second mode, which I call ‘participatory’ holistic science (Table 1), is also concerned with a trans-disciplinary understanding of emergent phenomena, but has a different philosophical motivation at its core. Drawing on the strengths of the pre-scientific world-view described above, and on contemporary approaches in cognitive science and in the philosophy of science, this mode of holistic science sees humans not as objective observers but as participatory 'experiencers' radically embedded in the world. Intrinsic value is explicitly recognised, and knowledge is seen as a means for increasing a sense of belonging to nature, rather than solely as a means for its control. This mode of science accepts lack of *complete* predictability as a key feature of a creative universe, as chaotic phenomena such as weather patterns, have clearly shown us. Furthermore, intuition is explicitly developed as a method for enhancing scientific enquiry through paying close attention to the consistency of feelings and intuitions which come up amongst a group of scientists during their investigations (Goodwin 1999).

Deep Ecology.

Participatory holistic science is more than just an intellectual stance - it involves a radical shift in our fundamental perception of nature. The shift is primarily experiential rather than intellectual, and is very well characterised by an experience recounted by the famous American ecologist Aldo Leopold in his book 'A Sand County Almanac' (Leopold 1949). Leopold was a wildlife manager in the first half of the last century, and supported a scientific program to eradicate the wolf from the United States so that hunters could have more deer to shoot. Then one day whilst out in the mountains with some friends he shot an old wolf, and scrambled down a steep slope to watch its last moments. In a chapter called 'Thinking Like a Mountain' he describes the shift in perception which he experienced during his encounter with the dying wolf:

"We reached the old wolf in time to watch a fierce green fire dying in her eyes. I realised then, and have known ever since, that there was something new to me in those eyes - something known only to her and to the mountain. I was young then, and full of trigger itch. I thought that because fewer wolves meant more deer, that no wolves would mean hunters' paradise. But after seeing the green fire die, I sensed that neither the wolf nor the mountain agreed with such a view".

Leopold had broken through the conditioning of his scientific training and had made contact with the life of the ecosystem *as a whole, in its own right.* He intuited that role of the wolf was to "fit the deer herd to the range", that without the wolf the deer would decimate the mountain ecosystem, and ultimately themselves. This perception allowed him to feel a deep empathy with the mountain and its more-than-human inhabitants, with a difficult-to-articulate sense of *agency* in these entities, which he could only describe using the crude approximation of teleological language. The point is that he was informed by an intuitive sense of the *intrinsic value* of the more-than-human beings which surrounded him, a value which inhered in them irrespective of their usefulness to his own species.

The Norwegian philosopher Arne Naess, who coined the term 'deep ecology', would say that Leopold had experienced the 'ecological self' - a state in which we identify with wider wholes beyond our everyday, narrow human self-centerdness. In this state of 'wide identification' our sense of concern and compassion includes the human realm, but expands beyond it, encompassing the entire scope of the more-than-human world (see Naess 1986, reprinted in Sessions 1995, pp. 225-239). The greatest circle of earth-bound identification which the ecological self can reach is Gaia, the whole planet as an emergent, living entity.

Deep ecology, which is as much a movement as a philosophy, seeks to help individuals to discover how life, both personally and at the level of society, can best be lived in accord with one's Leopold-like deep experiences of the more-than-human world. This requires a process of 'deep questioning' of oneself and society so that one becomes aware of one's own 'ecosophy', or ecological wisdom. There are many ecosophical paths, and Naess stress the importance of pluralism and tolerance along the long frontier of the deep ecology movement (Naess 1986).

Earth System Science and Gaian Science

How do these two modes of holistic science and deep ecology relate to scientific views of the Earth? The detached mode, when applied to understanding the Earth as a system could be identified with 'Earth System Science' (Table 2), a term which is rapidly gaining acceptance in the mainstream. It is not too far fetched to imagine that some Earth System scientists could see the Earth as a mechanism, albeit a hugely complex one, with instrumental value insofar as it provides 'ecosystem services' for sustaining human interests, and particularly continued economic growth. Indeed, some Earth System scientists have proposed projects in Earth System Engineering (Allaby 1999) to solve the problem of climate change by seeding the ocean with iron to encourage carbon dioxide drawdown by algae (see discussion in Allaby, op. cit.), or by placing a dam across the Strait of Gibraltar in order to modify oceanic and atmospheric circulation in the high northern latitudes (Johnson, 1997). Others have demonstrated that carbon capture at the source of fossil fuel burning is technically and economically feasible (Herzog and Drake 1996).

The participatory mode of holistic science is inspired by deep ecology and could be called 'Gaian Science' when applied to understanding the Earth. Gaian science would paraphrase Leopold by affirming that humans are 'plain members' of the Gaian community, and that detached observation and control are impossible due to our radical embededness in Gaia. Far from conceiving of the Earth as a machine, Gaian scientists *experience* it as an organism which is imbued with intrinsic value due to its own self-evident, awe-inspiring existence. Gaian scientists seek to gain knowledge in order to facilitate experiences of wide identification and deep participation in the life of Gaia, rather than to gain control of or 'engineer' Gaia's vital functions.

Gaian scientists would thus be highly critical of the kinds of global scale technical fixes outlined above since these arise from an acceptance of the current economic status quo rather than from a deep questioning of the underlying values and impacts of the globalised consumer culture. Those who do engage in such deep questioning broadly agree that ecologically friendly technologies implemented at the local scale have much to contribute. For example, they would consider it wiser to reduce our overall carbon emissions by implementing a steady-state, ecologically sustainable economy powered by the use of renewable energy sources, energy saving measures and other such practices rather than by pumping carbon dioxide from fossil fuel burning into underground reservoirs. Those engaging in deep questioning recognise that such an apparently benign solution could become problematic due to unpredicted leaks and discharges over a range of time scales. Furthermore, devoid of deeper ecological analysis, such technical fixes give the impression that economic growth can proceed apace once they are 'safely' implemented.

Final remarks

James Lovelock named his theory of a self-regulating planet after Gaia, the ancient Greek divinity of the Earth. The conventional scientific community strongly objected, even though Lovelock has taken great pains in his later writings to emphasise that he used Gaia as a metaphor, just as Richard Dawkins has used the metaphor 'selfish' when speaking about the behaviourof genes. Recently, Gaia theory has been re-branded 'Earth System science', which has appropriated most if not all of the main insights, ideas and results arising out of Lovelock's theory, thereby removing any recent reference to Gaia in scientific discourse.

However, for Gaian scientists the reference to the divinity of the Earth reminds us that science can no longer hold to the outdated and dangerous belief that humans can control nature, and urges science to participate in and serve both the human and the more-than human worlds. Gaian science leads us to participate in the reality of Gaia as an organism in the way the Aldo Leopold participated through his feelings in the lifeof the wolf and of the mountain. Gaian scientists, recognising that science cannot and should not be separated from moral, political and economic concerns, seek to deeply question and remould themselves and society based on their deep experiences of studying, living in and identifying with Gaia. A guiding principle for them is that human vital needs should be satisfied with as little disruption as possible with Gaian processes at all levels. Gaian science, as defined in this article, can thus be distinguished from Earth System science by its striving to bring a sound science of the Earth together with ecological wisdom and action.

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Tables

Table 1

Some differences in emphasis between two modes of holistic science.

Detached Holistic Science	***Participatory Holistic Science***
Detached observers of 'systems'	Participatory 'experiencers' embedded in the world.
Implicit instrumental values	Explicit intrinsic values
Knowledge for control	Knowledge as belonging
Intuition hardly acknowledged	Intuition as method

Table 2

Some possible distinctions between Earth System Science and my own proposal for a Gaian Science.

Earth System Science	***Gaian Science***
Humans as observers of the Earth	Humans as 'plain members' of the Gaian community
Earth as a machine	Gaia as an organism
Earth system has instrumental value	Gaia has intrinsic value
Earth system services sustain the human economy	Gaian system services sustain the web of life
Prioritises global scale technical fixes for global environmental	Prioritises local scale appropriate technology

problems	
Seeks not to become involved in the political implications of its findings.	Seeks to use its findings to foster ecologically sound life-styles and societies.