CREATIVE HOLOBIONTS: CONRAD WADDINGTON AND THE INTRA-ACTION OF SCIENCE, ART AND PHILOSOPHY

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ABSTRACT

This article takes the work and life of Conrad Waddington to illustrate the point that science, art and humanities can be mutually constituting fields that each bring light to aspects of reality that the others may not yet have the tools or the language for and that they can thereby work together to bring new revelations and progress. Borrowing a term from Lynn Margulis, I call this interaction a *Creative Holobiont.* The article puts Waddington's work on the development of organisms in the context of metaphysical questions of change and difference and describes his inspiration from the philosopher Alfred North Whitehead. It then moves on to touch upon later discoveries in biology which take us beyond the individual organism to a fully relational view of life. Finally, it discusses how this view has been represented in artistic works recently and in the past.

KEYWORDS

Waddington, Whitehead, Process Philosophy, Transdisciplinarity, Academia, Science, Biology

In Academia, the fields of natural science, humanities and art tend to be strictly separated. Furthermore, in the public there tends to be a bit of a hierarchy in the way they're valued. For example, politicians might value the "hard sciences" that lead to technological breakthroughs and innovation while the so-called "soft sciences" like humanities, philosophy or social studies are valued less or even vilified as peddlers of dangerous ideas that confuse and corrupt the youth. Meanwhile, the few artists who make it "big" might be glorified as unique geniuses but there isn't much consensus today that arts education should be supported by society and made available to everyone. This separation, and especially the hierarchical thinking, is a problem because science, humanities and art need each other and by working together they can create deeper understanding of the subjects. When they're thoroughly entangled, they can create something new and have the potential to become what I like to call a *creative holobiont*.

This is a term I appropriate from the biologist Lynn Margulis who used the word 'holobiont' to describe what's more than a symbiotic interaction between separate organisms. A holobiont is itself an organism that emerges through the entangled *intra-action*—concepts I borrow from Karen Barad—of organisms that are no longer separate. Like organisms, academic fields can be more than separate but interacting parts. I argue for a process model of science and academia where new knowledge emerges from the entanglement of various epistemic perspectives and methods.

The British biologist Conrad H. Waddington (1905-1975) embodied this concept. Waddington was a modern Renaissance intellectual: not only a pioneering biologist who coined the terms epigenetics and canalisation and initiated the field of systems biology, but also a philosopher who wrote about the biological implications of Alfred North Whitehead's (1861-1947) metaphysics and an art theorist who studied the relations between modernist visual art and discoveries in natural science. For Waddington, art does more than just reflect or represent reality and science; it can also inform scientific inquiry by prompting new ways of thinking and new conceptualisations. He was interested in forms of art that helped the visualisation of life as a dynamic process involving energies, indeterminacy, transformation and interaction rather than as linear and mechanistic.

I use the work and life of Waddington to demonstrate that, when done well, science, art and humanities can be mutually constituting fields that each bring light to aspects of reality that the others may not yet have the tools or the language for, and that they can thereby work together to bring new revelations. When the scientist is stuck, art and philosophy can help them move forward, just like art and philosophy can be inspired by scientific discoveries. I describe Waddington's work on the development of organisms and put it in the context of metaphysical questions of difference and change; then I describe his inspiration from the philosopher Whitehead and his thoughts on the relations between art and science. I then move on to touch upon discoveries in biology after Waddington—discoveries that take us beyond the individual organism to a fully relational view of life—and finally I discuss how this view has been represented in artistic works recently and in the past.

DIFFERENTIATION AND CHANGE: METAPHYSICS OF BIOLOGY

Waddington was first and foremost a pioneer of developmental biology, which is the study of how living things grow and take shape. Throughout his life, he published several books on this topic, such as *An Introduction to Modern Genetics* (1939), *Organisers & Genes* (1940), *How Animals Develop* (1946), *Principles of Embryology* (1956), *The Strategy of the Genes* (1957), *New Patterns in Genetics and Development* (1962), the 4-volume *Towards a Theoretical Biology* (1968–72) and *Principles of Development and Differentiation* (1966).[1] Before moving on, I want to use the title of the last book on this list to briefly explain what is philosophically interesting in the study of how living things develop: It's a process of *differentiation*, i.e. the process where something becomes different from something else or from what it previously was. This topic has been a matter of philosophical enquiry since the beginning of philosophy with Parmenides' (5th c. BCE) poem *On Nature* in which he questions the reality and possibility of change and difference: for something to become what it previously wasn't, it must move from not-being to being which makes it seemingly impossible to explain what made it arise later rather than sooner. It's this explanation that developmental and evolutionary biology search for: what makes things change and become different? Biology is thus dealing with some of the most fundamental questions of philosophy.

The Parmenidian view that change is impossible—or an illusion covering a more fundamental stability—dominated biology and science for centuries where biological species were considered permanent and immutable: if an organism appeared to differ from its true species-form that was just an example of the imperfect world of appearances. But with the advancement of evolutionary biology by scientists such as Charles Darwin (1809-1882) and Alfred Russel Wallace (1823-1913) it became increasingly clear that life is a process of continuous change and that the diversity of life that we know is a result of this constant change. Differentiation is foundational to evolution where members of one species undergo a process of becoming another, but it's also foundational to the development and growth of each organism. The first step of any animal is the zygote: a single fertilised egg cell that contains the genes of its parents and, in theory, all the factors that will determine its development. But a puzzle arises already in the embryonic form as the cell starts to divide itself through the process called "cleavage". This isn't a mere reproduction of itself because although each cell contains the same genetic material, they differentiate and become parts of different organs and body parts. This is the metaphysical mystery of biological development: how can a thing, whether a cell or a whole organism, become multiple different things despite having the same biological "essence"?

We'll return to this question but first, we'll resume the brief biography of Waddington. I don't know whether Waddington was directly aware of the problem of change posed by Parmenides, but he was certainly familiar with the broader philosophical debates. His childhood education consisted of chemistry but also of ancient Greek and Arabic philosophy and science,[2] and although he originally trained to be a palaeontologist at the University of Cambridge, he was also awarded the Arnold Gerstenberg Studentship created to promote "the study of Moral Philosophy and Metaphysics among students of Natural Science" and in 1929 he won the Arnold Gerstenberg Prize for an essay entitled "Philosophy and Biology" in which he discussed Whitehead's philosophy and its relevance to biology.[3]

Waddington continued to be interested in the connections between philosophy, ethics and science throughout his career as evidenced by several of his works such as *The Scientific Attitude* (1941), *Science and Ethics* (1942), *The Ethical Animal* (1960), *The Nature of Life* (1961) and *Tools for Thought* (1977), which all deal with the inter-related issues of ethics, biology, science, metaphysics and the moral responsibility of scientists. He also contributed two chapters on the relationship between philosophy and evolution to the book *Mind in Nature: the Interface of Science and Philosophy* (1977). He was interested in aesthetics and the relationship between art and science as well, as evidenced by his book *Behind Appearance: A Study in the Relationship Between Painting and the Natural Sciences in this Century* (1970), and throughout his scientific career he worked closely with artists.

THE EPIGENETIC LANDSCAPE: ILLUSTRATING UNCERTAINTY

Many scientists have some working relationship with artists, but for Waddington it wasn't merely a relationship of convenience where the scientist uses the artist to create visual illustrations of the scientific ideas in the form of diagrams or simplified figures to be digested by the public. For Waddington, the relationship was mutual, and the artist was as much a creator of ideas as the scientist. In the introduction to the posthumously published *Tools for Thought*, he wrote:

> [M]any people, including myself, find that it is often useful and enlightening to have visual illustrations of ideas. This book is therefore provided with a large number of diagrams. These are not intended to express facts about quantities of things, like the usual graphs one sees in scientific books. They are strictly illustrations of ideas, and their purpose is to stimulate your imagination to seize the gist of what an idea is about.[4]

The book is illustrated not by someone trained in technical representation but by the painter Yolanda Sonnaband (1935-2015) who, Waddington writes, "combines the intellectual capacity to grasp the ideas with the visual imagination to find a way of symbolizing them in drawings which are always pleasant, and sometimes beautiful."[5] Even more philosophically, in *Beyond Appearance*, he writes:

> The scientist does not go to the painter for a representation of scientific objects, but for the enrichment and deepening of his consciousness, which comes when he finds a painter in whom the climate of scientific thought has penetrated into the spirit, leading to the production of works in which some of the deeper, less easily expressible, features of the scientific outlook are 'shown forth'.[6]

This quote implies that, for Waddington, art isn't secondary to science; it doesn't just help the scientist express their ideas but also to *get* their ideas—or at least help them articulate the ideas that might otherwise have remained vague. This active role of art was part of

Waddington's work from the beginning. The frontispiece of one of his early works, *Organisers & Genes*, features a landscape drawing by the artist John Piper (1903–1992) which would come to define Waddington's intellectual career. Central in the drawing is a canyon with a rushing river and around it we see the topological features of the broader landscape with several smaller valleys leading towards the riverbank while the sky on the horizon is covered with rain clouds that also hint at the presence of wind. The use of shadows and lines gives the drawing a sense of depth, movement and dynamism.[7]

Waddington captioned the drawing "The Epigenetic Landscape" as it gave him an understanding of the dynamic development and differentiation of cells in an organism. If you imagine a drop of water landing somewhere in the landscape, you can make a qualified guess as to where it will eventually end up—in the river at the bottom of the canyon gushing towards the sea. But you also see that there are many alternative paths and that chance and other factors in the environment, like the wind or the grass, will play a part in shaping the trajectory. If the geological features of the landscape represent the genetic structure and the water represents a cell, then we have Waddington's concept of epigenetics: genetics make certain trajectories more likely, but the development of an organism also depends on environmental factors. *Epigenetics*—a term coined by Waddington—is the assemblage of all the factors that influence the development of an organism besides the genes, or rather in interaction with the genes.

This landscape metaphor stuck with Waddington and in the 1957 book, *The Strategy of the Genes*, he included his own simplified modification of it, which is the illustration that has become known as the Epigenetic Landscape where a ball is seen at the top of an abstract surface with various topological features: hills, valleys and slopes.[8] Here we can easily see that if the ball starts rolling, certain trajectories are more likely than others and also that once certain paths are taken others are ruled out, but we cannot from the beginning predict with accuracy which path the ball is going to take. Contrast that with the way cell development is often represented in popular and scientific media: as a linear trajectory with arrows from the fertilisation of an egg cell that splits into several cells in the embryo and eventually grows into a whole organism like a human being.[9] Here the first cell, the zygote, has all the DNA which is reproduced in the other cells. If DNA is considered the essence of each cell that contains all the "instructions" for their development, then nothing can go wrong; the development is fully predictable. But we know that organisms don't always develop as predictably as this simplified model implies, so often, when something goes wrong, the illustrations add another factor called "mutation". But the word mutation doesn't mean much other than that things didn't go as expected; it's not an explanation but what needs an explanation.

The simplified model implies a mechanistic and deterministic development that is set in stone from the beginning and the model breaks down when reality doesn't conform to that. Waddington's epigenetic landscape, on the other hand, has *unpredictability* built into it from the start. When we look at it, we intuitively grasp that although some trajectories are more likely, we cannot know for sure how the ball is going to roll. That's the power of an artistic illustration in which "some of the deeper, less easily expressible, features of the scientific outlook are 'shown forth'."[10] It is also the reason, I assume, that this illustration is still considered "the most famous and most powerful metaphor in developmental biology."[11]

FLUX AND RELATIONALITY: THE INSPIRATION FROM WHITEHEAD

Around the same time as the ancient philosopher Parmenides' argued that change is an illusion, another philosopher, Heraclitus, proposed the opposite: that everything changes or "flows". Instead of seeing the world as one indivisible substance, Heraclitus saw it as a constant movement of interacting forces, opposites and differences, out of which the more or less temporary things we interact with emerge. This discussion also relates to biology where we both want to know how organisms change and become different *and* why they still maintain some stability and similarity; it may be that everything changes but if it changed randomly all the time, then life wouldn't be possible. For a living system to maintain itself (*autopoiesis*) it needs a certain degree of stable conditions (*homeostasis*).

We can assume that Waddington was somewhat familiar with these ancient ideas because he was certainly well-versed in Whitehead's process philosophy which explicitly builds upon Heraclitus' phrase "everything flows", which Whitehead calls the notion of *flux*.[12] Whitehead sides with Heraclitus but also recognises the philosophers who have been occupied with the permanence of things, whether those things be "the solid earth, the mountains, the stones, the Egyptian Pyramids, the spirit of man, God." [13] It's true that the universe isn't just a chaotic flow in all directions; some things seem to have stability and solidity. Whitehead uses the term *concrescence* to describe the process of elements in flux coming together whereby an object begins to solidify and come into existence as a particular and somewhat stable entity.[14] This is similar to Waddington's idea of *canalisation* where a specific form comes into being and becomes stabilised.[15] This process is also captured in the Epigenetic Landscape where it is visible that although there is a degree of unpredictability, certain paths are more likely than others and once those paths are taken the possible developments become more constrained as the ball rolls down the hill or the organism takes shape.

Concrescence or canalisation is not to be confused with permanence, though. Concrescence is still an aspect of flux—change just happens at different timescales. Concrescence is Whitehead's name for the process where things or entities start to form and acquire an "individual unity" in the general flux.[16] This individual unity doesn't mean that the things are self-contained and atomistic or that they are permanent; every entity—or, as he also calls it: every actual occasion—exists as an aspect of the interactions and relations of everything else:

> The misconception which has haunted philosophic literature throughout the centuries is the notion of "independent existence." There is no such mode of existence; every entity is only to be understood in terms of the way in which it is interwoven with the rest of the Universe.[17]

Existence, to Whitehead, is thus always relational and what seems to be individual entities are merely temporary, more solid patterns that emerge from underlying processes. Whitehead wants to get rid of the idea that all of reality can be reduced to individual units of dead matter which is "senseless, valueless, purposeless."[18] If this is all there "really" is, then how do we get to a world of sensing, valuing, purposeful and, importantly, *living* beings? Materialistic reductionism misses something important. We don't get life by just combining more dead stuff and neither is it to be found in some other essential component unit (like the life-force of earlier vitalism). Life, Whitehead writes, is a characteristic of "empty space": "life lurks in the interstices."[19] What this means is that something happens in the space between the individual components—in their interactions and relations. Rather than reducing life to separate substances, the process view emphasises the relations and interactions out of which things, organisms and other entities, emerge. In the reductionist view the processes are determined and constrained by the substances which are themselves unchanging; nature is thus fixed and nothing new can emerge. But in the process view the entities that emerge from the processes change when the processes change, and processes are always dynamic and changing.

Waddington was part of a movement of biologists known as *organicists*. Like Whitehead, who also called his ideas "the philosophy of organism,"[20] they rejected the idea that the essence of a living creature could be reduced to any material component. Instead, they believed that life resulted from the reciprocal play of many elements which "lead all together to the final result."[21] Like the water in a river is constantly replaced while the river maintains its form, all the materials of an organism are regularly replaced through metabolism while the organism maintains its structure. Thus, biology isn't primarily the study of material things but about stabilised processes.[22] Against reductionism, which would give primary causal and ontological status to some specific biological component, organicists focus on the organism itself as an integrated and self-regulating whole that emerges through the interactions of the internal components. The organism isn't merely the *result* of these interactions; it's also a *cause* of them as each cell finds its place in this larger whole. Thus, organicism doesn't replace the upwards causation of mechanistic reductionism with holistic downwards causation but rather see the organism-cell relationship as a recursive process with regulation in both directions.[23]

Waddington continued and developed the theory of organicism in his 4-volume *Towards a Theoretical Biology* and in *The Theoretical Biology Club* which he co-founded. The target of this club was the emergent, mechanistic and reductionist, gene-centric view of evolution. Although he studied genetic inheritance, Waddington didn't believe that the development of an organism could be explained fully by reference to the genetic material in the cells. The differentiation of the cells and of each organism is also a result of the *interactions* between the cells and between the organism and its environment—the epigenetic factors. Nothing exists or develops in isolation. If our nature was determined exclusively by the DNA in the zygote, then our development would be fixed and mechanical; there wouldn't really be any change, just the unfolding of a preset program. But given that processes change when they interact with other processes nothing is really determined. Our natures aren't fixed. This has ethical implications for Waddington. As he writes in *The Scientific Attitude,* it is:

of the very greatest importance to realise that human nature is plastic, and can be shaped by society either for good or ill. If man were really an unregenerate and unimprovable brute, there would be no point in any cultural activities, or even in discussing the changes which could be made in society; what would be the purpose of making them if man himself became no better because of them?[24]

BEYOND WADDINGTON AND BEYOND THE ORGANISM

From the cellular point of view, organicism is thus the confirmation of Whitehead's claim that there is no "independent existence": every cell is only to be understood in terms of the way in which it is interwoven with the rest of the organism. Waddington's epigenetics also reminds us that we aren't predetermined from conception, as the unfolding of our bodies depends not only on our DNA but also on our interactions with the rest of the environment. We can take this relational view further, though: Since Waddington, landmark discoveries in biology mean that we can now go beyond the individual organism and its genetic makeup. Our cells and our DNA are the results of interactions between different lifeforms that predate our conception and our species. This interaction is constantly ongoing in each organism which is itself no longer conceived as merely the cells that contain one set of DNA but rather as a multispecies assemblage. Even at the species-level it is the case that there is no "individual existence."

The first discovery was made by the biologist Lynn Margulis (1938-2011) who, in 1967, hypothesised that certain parts (organelles) of the cells in multicellular organisms—the mitochondria, the photosynthetic plastids and the basal bodies of flagella—were once free-living prokaryotic organisms.[25] She speculated that over a billion years ago, an anaerobic unicellular organism ingested an aerobic microbe (possibly a bacterium). Rather than being fully digested this microbe became absorbed into the larger cell and eventually became the mitochondria that perform the vital function of converting oxygen into energy in all eukaryotes (which include all plants, animals and fungi). Similar events, she proposed, resulted in the plastids that gave plants the ability to convert sunlight into energy (photosynthesis) when a eukaryotic cell ingested cyanobacteria, and the flagella which gives certain cells their power of propulsion, when an amoeboid organism ingested or became host to a motile parasite. While some of these proposed mergers is disputed, others are generally accepted today, and they form the basis of the endosymbiotic theory of evolution, or *symbiogenesis,*[26] which proposes that complex lifeforms emerged through the symbiotic mergers of other lifeforms: Interactions of differences that create something new.

The second discovery is also related to microbiology and DNA sequencing but concerns life in the present rather than in the evolutionary past. In recent decades, technological advances have enabled classification of the thousands of types of microbes living in the human body, and in all other multicellular organisms. We have learned that they perform essential functions in our anatomy: bacteria and other microbial beings regulate our metabolism and immune system and are among the epigenetic factors Waddington was searching for that influence gene expression and the development of the organism.[27] Some of them we are born with, others we acquire throughout our lives, and we could not live without them. This puts a radical parenthesis around the "germ theory of disease"—not because there are no diseases caused by infections from germs but because of the associated idea that all germs, or microbes, are "bad" and that one should avoid anything from the "outside" infecting the "inside."[28] We now know that we need many of these beings from the outside to become part of our inside; the functions they perform are so vital for our being, that it wouldn't be a stretch to say that they don't merely live *within* us—they *are* us and we are *them*. Together we form, what Lynn Margulis has called a *holobiont*.[29] A holobiont is more than different creatures living in symbiosis (symbionts) but a whole new being that comes out of the interaction of and with other beings. The process-philosophical and relational implications of this new understanding of life come to the fore in this statement by Margulis:

> The life-centered alternatives to mechanistic neo-Darwinism recognize that, of all the organisms on Earth today, only prokaryotes (bacteria) are individuals. All other live beings ("organisms"—such as animals, plants, and fungi) are metabolically complex communities of a multitude of tightly organized beings. That is, what we generally accept as an individual animal, such as a cow, is recognizable as a collection of various numbers and kinds of autopoietic entities that, functioning together, form an emergent entity-the cow. "Individuals" are all diversities of coevolving associates.[30]

As argued by Rees, Bosch & Douglas, these new insights from biology are rapidly changing the life sciences but the implications are having a harder time reaching into the humanities, which they should because "the finding that microorganisms are a constitutive part of ourselves calls for a new configuration of the effort to understand what it means to be human."[31] The scientific fact that we aren't separate individuals or separate organisms should have immense consequences for philosophy, sociology, anthropology, history, politics, ethics and all other fields within the human sciences. The division between natural science, art and humanities came from the idea that there's something that sets humans apart from other living creatures and from nature itself and that our activities are somehow uniquely human.[32] The realisation that what we are and what we do is never an isolated "human" activity, and neither is it ever an individual activity, has the "potential to catalyze the breakdown of the anachronistic barriers between the natural and the human sciences and enable a truly integrated understanding of what it means to be human, after the illusion of the bounded, individual self."[33] The blurring of the distinction between organisms thus calls for the blurring of the distinction between academic disciplines.

CREATIVE HOLOBIONTS: FROM INTERACTION TO ENGAGEMENT

Waddington and Whitehead's biology and philosophy were in many ways companions to radical changes in science occurring at the time. Newtonian physics based on independent atomic units was being challenged by quantum physics based on interacting forces and entanglement, and a deterministic view of the world governed by universal mechanical laws was unsettled by one dominated by uncertainty, relativity, and observer-dependence. The scientific discoveries and debates by figures like Albert Einstein (1879-1955), Niels Bohr (1885-1962), Werner Heisenberg (1901-1976) and Erwin Schrödinger (1887-1961) reinvigorated philosophical metaphysics, which had otherwise been proclaimed dead by the logical positivists, shaped the public conversation and influenced art and culture. That was the topic of Waddington's book *Behind Appearance* in which he explores the relationship between contemporary art and science.

The thesis of this book is that both the arts and the sciences had departed from describing or representing external appearances to "penetrate behind the surface of things, into the energetic existence of matter in space-time."[34] The book is an impressive catalogue of visual artists and artistic movements in the 20th century—from Cubism, Bauhaus and Surrealism to Mark Rothko (1903-1970), Jackson Pollock (1912-1956) and Andy Warhol (1928-1987)—combined with analyses of the various ways they express and use aspects of science from mathematics to quantum physics. This work, and Waddington's relationship to art in general, is described in detail by Katharina Lee Chichester who notes that the most striking aspect is Waddington's insistence that art doesn't merely express scientific ideas but also has epistemic value to science:

> Beyond producing works that resemble scientific images, painters, according to Waddington, create sensual experiences by means of aesthetic experiments that aid in the discovery of new patterns in nature and help scientists grasp the meaning of their own theories and findings more deeply.[35]

The concept of "interdisciplinarity" has become a positive buzzword in academia in recent decades and many research projects include participation from different academic fields, including artists. But often this amounts to little more than that the researchers work separately on a common topic with little interaction between them. Thereby, the disciplinary academic boundaries are reproduced in a smaller scale within these research projects. Waddington's approach to science, philosophy and art was different: He thought that they expressed in different ways aspects of the world that they each, in isolation, could have difficulty grasping and that together they can create a deeper understanding and new ideas. This suggests that we need more than interdisciplinarity. We need what Karen Barad calls *intra-action*. This concept differs from interaction, which "assumes that there are separate individual agencies that precede their interaction," in that "the notion of intra-action recognizes that distinct agencies do not precede, but rather emerge through, their intra-action."[36] This concept is clearly related to Whitehead's process philosophy, as is also evident in Barad's notion of entanglement:

> To be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence. Existence is not an individual affair. Individuals do not preexist their interactions; rather, individuals emerge through and as part of their entangled intra-relating.[37]

Furthermore, Barad's descriptions of intra-action and entanglement resemble the relational, organismic and holobiontic view of life expressed by biologists like Waddington and Margulis. A holobiont is not merely the joining and interaction of separate entities or organisms—that would merely be symbiosis—but a new life-form that emerges as part of the entanglement, intra-relating and reciprocal play of several elements. An integrated and intra-relating approach that combines science, art, philosophy and other epistemic approaches—not as separate activities that preexist their interactions but as intra-acting and entangled elements that together form something new—is what I call a *creative holobiont*.

Science can and has always informed and inspired art and the humanities. Likewise, scientists have, whether consciously or unconsciously, been influenced by philosophy in their formulations of hypotheses, models and explanations. Art is not always recognised as much more than a tool to explain the science and the philosophy to 'the public' or as a something that can awaken their inspiration and admiration for the topics. For Waddington, art also has the ability to articulate ideas that are sometimes vague even to the scientists—perhaps not much more than a 'felt sense'[38]—and to help them see and understand their own ideas better. A process model of the sciences suggests that when the different fields intra-act from the beginning something new might emerge.

Of course, there have been points of convergence between these fields. The philosopher Donna Haraway is trained as a zoologist and wrote her dissertation on Waddington and the organicist school of biology.[39] She also draws heavily upon Margulis in her philosophy of *kinmaking* and *sympoiesis*.[40] Likewise, many artists and art theorists have found inspiration in Donna Haraway's Whiteheadian philosophy[41] and in the biological discoveries of scientists like Margulis (see for example the painting by Shoshana Dubiner *Endosymbiosis: Homage to Lynn Margulis*). Focusing on the Nordic countries, the Medical Museion in Copenhagen hosted an exhibition called *The World is in You* in 2021-2022 which explored how our bodies are affected by their environment. This exhibition utilised biomedical research on the microbiome as well as a multitude of art pieces.[42] A multidisciplinary research project on "Human-Microbial Relations in Everyday Life" hosted at the University of Iceland focuses on the scientific and cultural use of microbes in food but also investigates people's spiritual connection to the Earth as they compost.[43] Meanwhile, artists like Gemma Anderson-Tempini are working to extend Waddington's epigenetic landscape and continue his exploration of how drawing can help expand scientific insights,[44] while Heather Barnett uses photography and video to illustrate how the single-celled superorganism, slime mould, explores and navigates its environment intelligently in dynamic processes that take place at different tempi than what humans are used to.[45] Barnett exhibited her work, together with several other international artists who all work in the intersections of art and science at the exhibition *Organic Circuits* at LÁ Art Museum in Hveragerði, Iceland.

It is thus not that no such work is being done. On the contrary, it's a growing field. At the same time, the awareness of the interconnected nature of humans and other living beings isn't a new discovery—humans have always known that we're more than a single organism! This knowledge has been expressed in every culture on the planet in some form or another through animistic totemism centred around the knowledge of kinship between humans and other animals: from Scandinavian Bronze and Iron Age paintings of bird-men and jewellery in which human faces are intertwined with animal bodies, to the elaborate transformation masks and totem poles of First Nations people in the American Northwest, and all the way to the southern hemisphere, hybridity and human-other-animal entanglements have been central themes in traditional art.[46] This reflects a deeper knowledge of relationality that our ancestors had and which some of us might have forgotten. This is knowledge that we can bring back, but that requires more than academic publications and museum exhibitions. It requires truly creative holobionts who can not only interact but also *engage* with general culture to bring relationality and connectivity back as core motifs in our collective consciousness.[47] Such work is crucial in a time of environmental poly-crisis where we all need to truly grasp, not just at a theoretical level but deeply in our being, that we are entangled with our environment and with other beings and that we need to relate to nature as part of us, not as separate from us. In the words of Whitehead, we need to realise that humanity's existence is not an individual affair.

1 C. H. Waddington, *An Introduction to Modern Genetics* (Macmillan, 1939); *Organisers & Genes* (Cambridge University Press, 1940); *How Animals Develop* (Allen & Unwin, 1946); *Principles of Embryology* (Macmillan, 1956); *The Strategy of the Genes: A Discussion of Some Aspects of Theoretical Biology* (Allen & Unwin, 1957); *New Patterns In Genetics & Development* (Columbia University Press, 1962); *Towards a Theoretical Biology 1: Prologema* (Edinburgh University Press, 1968); *Towards a Theoretical Biology 2: Sketches* (Edinburgh University Press, 1969); *Towards a Theoretical Biology 3: Drafts* (Edinburgh University Press, 1970); *Towards a Theoretical Biology 4: Essays* (Edinburgh University Press, 1972); *Principles of Development and Differentiation* (Macmillan, 1966).

2 C. H. Waddington, *The Evolution of an Evolutionist* (Cornell University Press, 1975), 2.

3 K. Lee Chichester, "Conrad H. Waddington and the Image of Process Biology," in *Drawing Processes of Life: Molecules, Cells, Organisms*, ed. Gemma Anderson-Tempini and John Dupré (Intellect Ltd, 2024), 19.

4 C. H. Waddington, *Tools for Thought* (Paladin, 1977), xiii.

5 Waddington, *Tools for Thought*, xiii.

6 C. H. Waddington, *Behind Appearance: A Study of the Relations between Painting and the Natural Sciences in This Century* (Edinburgh University Press, 1969), 155.

7 Waddington, *Organisers & Genes*, frontispiece.

8 C.H. Waddington, *The Strategy of the Genes: A Discussion of Some Aspects of Theoretical Biology* (Allen & Unwin, 1957), 29.

9 Examples are abundant but there's no need to call out a particular scientific paper as an example of a simplistic illustration.

10 Waddington, *Behind Appearance*, 155.

11 James E. Ferrell, "Bistability, Bifurcations, and Waddington's Epigenetic Landscape," *Current Biology* 22, no. 11 (2012): R458–66, https://doi.org/10.1016/j.cub.2012.03.045.

12 Alfred North Whitehead, *Process and Reality* (The Free Press, 1978), 208.

13 Whitehead, *Process and Reality*, 208.

14 Whitehead's use of the term concrescence is complex. For an overview, see John W. Lango, "Towards Clarifying Whitehead's Theory of Concrescence," *Transactions of the Charles S. Peirce Society* 7, no. 3 (1971): 150–67.

15 Mark L. Siegal and Aviv Bergman, "Waddington's Canalization Revisited: Developmental Stability and Evolution," *Proceedings of the National Academy of Sciences* 99, no. 16 (6 August 2002): 10528–32, https://doi.org/10.1073/pnas.102303999.

16 Whitehead, *Process and Reality*, 211.

17 Alfred North Whitehead, *Essays in Science and Philosophy* (Rider and Company, 1948), 64.

18 Alfred North Whitehead, *Science and the Modern World* (Pelican Mentor Books, 1948), 18.

19 Whitehead, *Process and Reality*, 105.

20 Whitehead, *Process and Reality*, xi.

21 Yves Delage, cited in Joseph Needham, "Organicism in Biology," *Journal of Philosophical Studies* 3, no. 9 (1928): 29–40.

22 John Dupré and Daniel J. Nicholson, "A Manifesto for a Processual Philosophy of Biology," in *Everything Flows: Towards a Processual Philosophy of Biology*, ed. Daniel J. Nicholson and John Dupré (Oxford University Press, 2018), 8.

23 Today this view is called "systems biology" and a brilliant explanation of it is found in Denis Noble's *The Music of Life: Biology Beyond Genes* (Oxford University Press, 2006).

24 C. H. Waddington, *The Scientific Attitude* (Penguin Books, 1948), 26.

25 Sagan (later Margulis) "On the Origin of Mitosing Cells," *Journal of Theoretical Biology* 14, no. 3 (1 March 1967): 225-IN6, https://doi.org/10.1016/0022-5193(67)90079-3.

26 Boris Mikhaylovich Kozo-Polyansky, *Symbiogenesis: A New Principle of Evolution*, ed. Lynn Margulis, trans. Victor Fet (Harvard University Press, 2010).

27 For a summary of examples, see Scott F. Gilbert, Jan Sapp, and Alfred I. Tauber, "A Symbiotic View of Life: We Have Never Been Individuals," *The Quarterly Review of Biology* 87, no. 4 (2012): 325–41, https://doi.org/10.1086/668166.

28 See e.g. David Griffiths, "Queer Theory for Lichens," *UnderCurrents: Journal of Critical Environmental Studies* 19 (13 October 2015): 36–45, https://doi.org/10.25071/2292-4736/40249; and Pierre-Olivier Méthot and Samuel Alizon, "What Is a Pathogen? Toward a Process View of Host-Parasite Interactions," *Virulence* 5, no. 8 (2014): 775–85, https://doi.org/10.4161/21505594.2014.960726.

29 Lynn Margulis, "Symbiogenesis and Symbionticism," in *Symbiosis as a Source of Evolutionary Innovation: Speciation and Morphogenesis*, ed. Lynn Margulis and René Fester (MIT Press, 1991), 2.

30 Lynn Margulis, "Big Trouble in Biology: Physiological Autopoiesis versus Mechanistic Neo-Darwinism," in *Slanted Truths: Essays on Gaia, Symbiosis and Evolution*, ed. Lynn Margulis and Dorion Sagan (Springer, 1997), 273.

31 Tobias Rees, Thomas Bosch, and Angela E. Douglas, "How the Microbiome Challenges Our Concept of Self," *PLOS Biology* 16, no. 2 (2018): 4, https://doi.org/10.1371/journal.pbio.2005358.

32 "Humanities," in *Encyclopaedia Britanica*, accessed 11 January 2025, https://www.britannica.com/topic/humanities. In *The Closing of the American Mind* (Simon & Schuster, 1987) Allan Bloom writes that the difference between social sciences and humanities is that "social science really wants to be predictive, meaning that man is predictable, while the humanities say that he is not" (p. 357). As we have seen, Waddington's works challenges this distinction as he insists on unpredictability even in the natural sciences.

33 Rees, Bosch, and Douglas, "How the Microbiome Challenges Our Concept of Self," 6.

34 Chichester, "Conrad H. Waddington and the Image of Process Biology," 12. This is reminiscent of Gilles Deleuze's statement that the "task of painting is defined as the attempt to render visible forces that are not themselves visible." Gilles Deleuze, *Francis Bacon: The Logic of Sensation*, trans. Daniel W. Smith (Bloomsbury Academic, 2003), 56.

35 Chichester, "Conrad H. Waddington and the Image of Process Biology," 13.

36 Karen Barad, *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (Duke University Press, 2007), 33. Whitehead uses the term "internal relations" to refer to relations that ontologically precede and constitute the relata (another point of convergence between Whitehead and Barad), *Process and Reality*, 59.

37 Barad, *Meeting the Universe Halfway*, ix.

38 Eugene Gendlin, "Introduction to Thinking at the Edge," *The Folio* 19, no. 1 (2004): 1–8.

39 The title of Haraway's dissertation was "The Search for Organizing Relations: An Organismic Paradigm in Twentieth-Century Developmental Biology," later published as *Crystals, Fabrics, and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology* (Yale University Press, 1976).

40 See e.g. chapter 3 in Donna J. Haraway, *Staying with the Trouble: Making Kin in the Chthulucene* (Duke University Press, 2016); and p. 31 in *When Species Meet* (University of Minnesota Press, 2008).

41 A search on this journal's website reveals 7 articles that mention Haraway published in *The Nordic Journal of Aesthetics* in the years 2018-2024.

42 Adam Bencard, Malthe Kouassi Bjerregaard, and Jacob Lillemose, eds., *The World Is in You: Documentation, Reflections, Lessons* (Medical Museion, 2022).

43 See Helga Ögmundardóttir and Eysteinn Bragason, "Compostories: Exploring Narratives of More-than-Human Relations in Soil Communities," *Cultural Analysis* 22, no. 2 (2024): 17–36, as well as the other articles in the same issue of *Cultural Analysis*.

44 Gemma Anderson-Tempini, Berta Verd, and Johannes Jaeger, "Drawing to Extend Waddington's Epigenetic Landscape," in *Drawing Processes of Life: Molecules, Cells, Organisms*, ed. Gemma Anderson-Tempini and John Dupré (Intellect Ltd, 2024), 83–98; Gemma Anderson-Tempini, *Drawing as a Way of Knowing in Art and Science* (Intellect Ltd, 2018).

45 Heather Barnett, "Drawing Out the Superorganism: Artistic Intervention and the Amplification of Processes of Life," in *Drawing Processes of Life: Molecules, Cells, Organisms*, ed. Gemma Anderson-Tempini and John Dupré (Intellect Ltd, 2024), 201–26.

46 Rune Hjarnø Rasmussen, "The Nordic Raven Totem," Nordic Animism, 2021, https://nordicanimism.com/blog/the-nordic-raven-totem.

47 Two examples of this cultural work could be Danish author Rune Engelbreth Larsen who recently published the tome *Animisme - Fra Klippekunst Til Klimakrise* (Dana, 2025) and the scholar-activist Rune Hjarnø Rasmussen who works in multi-artistic ways to recover traditional knowledge of creating and maintaining land-connectedness and kinship with other-than-humans (https://nordicanimism.com). One could also consider the Icelandic campaign to have the glacier Snæfellsjökull nominated for the 2024 presidential elections as a way to publicly engage with the personhood and rights of more-than-human nature (see https://kjosumjokul.com/).