INTERNATIONAL JOURNAL OF JUNGIAN STUDIES, 2018
https://doi.org/10.1080/19409052.2018.1441890

Routledge
Taylor & Francis Group

The Synthetic Cell as a Techno-scientific Mandala: a Jungian Analysis of Synthetic Biology Research

H. A. E. (Hub) Zwart

Department of Philosophy and Science Studies (Chair), Faculty of Science, Institute for Science in Society (ISiS), Radboud University Nijmegen, Nijmegen, Netherlands

ABSTRACT

This paper analyses the technoscientific objective of building a synthetic cell from a Jungian perspective. After decades of fragmentation and specialisation, the synthetic cell symbolises a turn towards restored wholeness, both at the object pole (putting the fragments together again) and at the subject pole (synthetic biology as a converging field, a Gesamtwissenschaft, fostering individuation). From a Jungian perspective, it is no coincidence that visual representations of synthetic cells often reflect an archetypal, mandala-like structure. As a symbol of restored unity, the synthetic cell mandala compensates for technoscientific fragmentation via active imagination, providing a visual aid for the technoscientific turn towards reintegration. Although the biotechnological desire to reconstruct life in vitro has been compared to alchemy before, a Jungian analysis allows us to make this comparison more specific and precise. The problem of archetypal images, however, is that alluring prospects of reintegration may underestimate and obfuscate the deficiencies and tensions at work in the current situation. As a projection of a future wholeness, it fosters optimism, but may also function as a misleading façade, covering up collisions and complexities. This can be averted by the conscious employment of the mandala as a symbolic scaffold fostering processes of individuation and working through.

ARTICLE HISTORY
Received 21 November 2017
Accepted 14 February 2018

KEYWORDS
Synthetic biology; synthetic cell; Jungian psychoanalysis; psychoanalysis of science; continental philosophy of science; Jung and science

Introduction

The adjective 'synthetic' in 'synthetic biology' suggests a dialectical schema which, in outline, runs as follows. Initially, living nature was perceived in a holistic manner. This position was exemplified by the philosophy of Aristotle (1986), who saw living beings as 'hylemorphic' entities, composed of matter (ὕλη) and form (εἶδος): the *first moment* (M_1) of the dialectical process. Subsequently, however, even Aristotle already realised that, in order to really understand living beings, they had to be opened up, dismantled and dissected (Aristotle, 1965, 496a11; 511b11–23): the beginning of anatomy as an empirical science. And this unleashed the *second moment* (M_2) of the dialectical process, the moment of negativity, for (paradoxically perhaps) in order to understand living beings, they apparently

CONTACT H. A. E. (Hub) Zwart h.zwart@science.ru.nl

Note: This paper has been typeset and published by the previous publisher and hence differs in appearance to other papers in this issue.

had to be demolished and taken apart. This idea was endorsed in an even more radical manner by modern science. Living beings (such as a tree, for instance) were reduced to their basic molecular components, so that the tree as a visible, tangible gestalt became 'obliterated' (Zwart, 2016), that is: replaced by chemical letters and symbols (CO_2, H_2O; $C_6H_{10}O_5$; A, C, G and T, etc.), broken down into basic components, representable with the help of formulas and letters. Ultimately, towards the end of the millennium, during the 1980s and 1990s (the genomics era), life basically came to be understood in terms of biomolecular barcodes.

From this perspective, synthetic biology (as a twenty-first century, post-millennial research field) can indeed be regarded as the *third moment* (M_3), the 'negation of the negation', as Hegel (1807/1973) phrased it: the return of the whole, but now on a higher level of epistemic complexity, aggregation and sophistication, trying to put the biomolecular pieces together again. And whereas modern science (during the *second moment*) had dispersed into a plethora of highly specialised fields, synthetic biology represents the third moment also in the sense that it is a converging endeavour, joining these various research fields together again into an overarching research programme, a *Gesamtwissenschaft*.

As Tomita (2001) and others have claimed, moreover, the final objective and major challenge of synthetic biology is the production of a (fully functional and self-replicating) synthetic cell. As an embedded philosopher, the author of this paper is involved in a synthetic cell project, namely the BaSyC project, an acronym which stands for *Building a Synthetic Cell*.[1] The building of a synthetic cell is not only seen as a technological, but also a philosophical experiment. The BaSyC project is driven by the idea that we can only claim to really understand life (more specifically: the living cell) once we are able to technologically reproduce it *in vitro*.

In this paper, the synthetic cell endeavour will be assessed from a Jungian perspective. While the building of a synthetic cell will be regarded as a process of individuation, the fact that representations of the envisioned synthetic cell quite consistently suggest a mandala-like structure is no coincidence. For indeed, according to Carl Gustav Jung (1944/1968, 1950/1959), the mandala is the archetype of recovered wholeness and completion.

To begin with, I will outline the *first moment* in the Western history of understanding living nature (M_1), namely the Aristotelian position of holism. Yet, Aristotle already acknowledges that living beings can be understood not only as materialisations of a basic *form*, but also as realisations of a *programme*. This concurs with a distinction between two types of thinking, namely imaginative and logical thinking, which was later elaborated by Carl Gustav Jung and Gaston Bachelard, a French philosopher of science who was significantly influenced by Jung. Modern science, however, with its 'iconoclastic' tendency towards quantification and formalisation, represents the *second moment* in the Western understanding of living nature, namely the moment of negativity (M_2). In the course of the twentieth century, living beings (as visual and tangible entities) were reduced to their elementary biomolecular components (the barcodes of life). Synthetic biology, however, as a post-millennial converging field, represents a recovery of the whole, a turn towards reintegration (M_3), both at the object pole (the synthetic cell as a symbol of restored unity) and at the subject pole: the synthetic cell endeavour as a process of transdisciplinary convergence (on the collective level) and of individuation (at the level of the self). This explains the pivotal role of archetypal mandala-like structures

in synthetic biology discourse. They symbolise the return of the whole and compensate for fragmentation.

Aristotle: two types of thinking and the holistic view of life (M_1)

Aristotle (1986) regards living beings as composites of form and matter, and as realisations or actualisations (ἐντελέχεια, 412a) of a basic formula or plan (λόγος, 412b, 415b). Moreover, a human being (as a logical animal: ζῷον λόγον ἔχον) may intellectually discern the *form* (εἶδος) or *formula* (λόγος) that constitutes a living being (Aristotle, 1986, 402a, 415b). As rational animals, humans are able to grasp the intelligible λόγος pervading living nature. In retrospect, Max Delbrück (the founding father of the molecular life sciences) credited Aristotle with having anticipated 'the principle implied in DNA' (1971, p. 55). For whereas, in modern biological terms, the *form* (εἶδος) of living beings corresponds with their phenotype (their morphological form or visual appearance), the plan or *formula* (λόγος) corresponds with the genome: the molecular programme that *realises* itself in a particular organism.

According to Aristotle (1986), the distinction between the visual form (εἶδος) and the logical plan (λόγος) of living beings is also reflected in our understanding of them. On the one hand, Aristotle sees human understanding as a continuation of visual perception. Whereas our eyes perceive living entities as compounds of matter and form, human understanding is focussed predominantly on the form (εἶδος) stripped of matter (ὕλη), so that thinking is a more abstract version of sense perception. In other words, whereas perception focusses on external things (πράγματα), the human thinking soul reflects on the inner images (φαντάσματα). But instead of on the *form* (εἶδος) of living beings, human thinking may also focus on their *formula* or plan (λόγος). Seen from this perspective, Aristotle argues, human understanding is comparable to reading letters (γραμματείον, 430a). In other words, thinking in the sense of considering formula is comparable to mentally reading or writing a text. Thus, Aristotle introduces a distinction between two types of thinking, namely thinking as considering mental *images* (φαντάσματα) versus thinking as deciphering mental *characters* (γράμματα). And whereas the former is focussed on the visual 'form' (εόδος), the latter is focussed on the 'formula' or plan (λόγος), realised in the actual organism.

Aristotle himself explains the difference with the help of an example. If we see a beacon, we initially recognise it as fire: an entity with a particular, recognisable, visual form, until it begins to move, for then we realise that it actually is a signal signifying something (for instance: the approach of a vessel). Thus, Aristotle already makes a distinction between fire as a gestalt (*image*) and fire as a *symbol*, i.e. an element in an alphabet of signals, bearing a human signature.

This distinction resurges in the work of Carl Gustav Jung (1911/1968), namely as the distinction between imaginative and rational thinking. While imaginative thinking builds on mental images (Aristotle's φαντάσματα), rational thinking is guided by concepts, words and logic (Aristotle's γράμματα). And whereas imaginative thinking occurs spontaneously, that is: under the sway of primordial archetypal forms, rational thinking operates with the help of linguistic, logical and mathematical operators (and is therefore more demanding and exhausting, mentally speaking). Imaginative thinking is the oldest form of thinking and reflects the spontaneous functioning of the human mind. According to Jung,

archaic worldviews are basically elaborations of a priori, archetypal forms (1954/1959a, p. 6). Rational thinking, however, is a relatively recent acquisition. Important intellectual developments, ranging from the invention of reading and writing via scholasticism up to modern science, have contributed to its current dominance. Notwithstanding the fact that a basic incompatibility can be discerned between the two, however, logical thinking has never completely replaced or erased imaginative thinking, so that the tension (the dialectics) between both types of thinking continues to unfold.[2] In fact, Jung argues that we should strive for a synthesis. Rather than falling under the sway of unconscious archetypal images by ignoring or repressing them, we should actively try to come to terms with them and integrate them, in the context of the individuation process, which requires a 'synthetic process', a 'dialectical procedure' (1954/1959a, p. 40).

In the history of bio-scientific research, a similar tension, a similar dialectics can be discerned. During the past three centuries or so, the *focus* of research has shifted from the visual shape (εἶδος, the object of morphology) to the symbolic (to the plan, the programme, the code; the λόγος of life). During the eighteenth and nineteenth century, biology was still oriented towards exploring the visual, morphological forms or structures of organisms: the *gestalt* of living entities, as exemplified by the work of Goethe (1817/1824). In the twentieth century, however, bioscience became focussed on the biomolecular codes and programmes of living systems: on the symbolic dimension, the λόγος dimension.[3]

This distinction can be further elucidated by comparing two close scholarly colleagues who studied plant life simultaneously more or less (during the 1850s and 1860s), in the same monastery at Brno, albeit in completely different manner (Zwart, 2008), namely Franz Bratranek (1815–1884) and Gregor Mendel (1822–1884). Mendel was interested in enigmatic 'elements' or 'factors' (currently known as 'genes'), whose presence or absence determined the visible features (the phenotype) of plants. In Mendel's famous publication (1866/1913), these elements are represented with the help of letters (Aa, Bb, Cc, etc.), where upper-case letters represent the dominant factor and lower-case letters the recessive factor. In other words, Mendel was focussed on the symbolic or λόγος dimension, the γράμματα of life. Mendel's colleague Franz Bratranek, however, was a Goethe scholar (editor of Goethe's correspondence with natural scientists such as Alexander von Humboldt, for instance) and opted for a different approach. In 1853 he published a remarkable book, *Beiträge zu einer Ästhetik der Pflanzenwelt* [Contributions to the aesthetics of plant life] in which he presented nature as a landscape, a meaningful *whole*; while a particular plant form might give a particular landscape an identity, a face. In other words, typical plant forms reflect a landscape's physiognomy. And poets will write about this particular plant (an oak tree, for instance) in order to articulate the mood that is invoked in them by the landscape type in question (a middle-European forest, for instance). Bratranek's view of nature explicitly relied on the ideas of Goethe, but also on alchemy. He agreed with Paracelsus, for instance, that a profound correspondence can be discerned, not only between humans (poets) and plant forms, but also between, for instance, flowers and stars.[4] Stars constitute a heavenly, sidereal garden, Bratranek argued, while both starry and vegetable flowers may have a 'magical' influence on us (1853, p. 14). This correspondence was part of a cosmic parallelism that existed between the various spheres of reality: the mineral, the vegetable, the animal, the human, the planetary and the sidereal sphere.

In the twentieth century, the Goethean emphasis on visual form (εἶδος) became eclipsed by the obsessive goal of deciphering the programme or code (λόγος) of life. In other words, the twentieth century sided with Mendel rather than with Bratranek. According to the French psychoanalyst of science Gaston Bachelard, whose oeuvre builds on the work of Jung,[5] this concurs with what he refers to as the 'iconoclastic' tendency of modern science (Bachelard, 1947, p. 77; 1953, p. 122). Bachelard was a Jung-adept who developed a psychoanalytical diagnostics of modern science, focussing on chemistry, physics and biology. Although from a scholarly point of view his references to Jung's work are often fairly general and imprecise, or even incorrect (Huskinson, 2013), Bachelard's frequent use of archetypal concepts (Mother Earth, Anima, Animus, etc.) is evidently inspired by Jung's work on alchemy as an imaginative and comprehensive form of inquiry predating the 'epistemological rupture' which gave rise to modern science (Bachelard, 1947), – although the medieval or early modern alchemist continues to exist beneath the surface of the modern technoscientific engineer (Bachelard, 1938/1949, p. 14). On the one hand, Bachelard emphasises the hostility of modern science towards the imaginary, towards archetypal images and the various mythological, poetic and religious worldviews that rely on them. At the same time, Bachelard analyses how, in modern times, the imaginary (the archetypes, the imaginative style of thinking) found a refuge in literary documents, in poetry and novels. The imaginary cannot be repressed once and for all and will continue to resurge, even in scientific discourse itself. For indeed: scientists are prolific producers of images themselves.

Scientific iconoclasm (M_2, *subject pole*)

Iconoclasm was inaugurated by Pharaoh Akhenaten (ca. 1353–1336 B.C.) and subsequently taken up by Judaism, Islam and Christianity (notably Protestantism) but, according to Bachelard, iconoclasm also became a distinctive feature of modern science (1947, p. 77; 1953, p. 122). The objective of science is to understand nature or natural entities, but instead of *letting nature be* (as in the case of artistic meditation or poetic exaltation), Bachelard explains how science, as a highly technical, laboratory pursuit, actively *transforms* natural entities into something abstract: e.g. bio-chemical molecules and processes, captured in formulas, symbols, equations and the like, with the help of laboratory equipment. As a result, the initial object, the visible natural phenomenon or *Gestalt*, becomes lost in measurements and quantifications, becomes obliterated, as we have seen. Due to this process of symbolisation and obliteration, living beings disappear from view. Because of the iconoclastic tendency of techno-science, their visual form (εἶδος) becomes erased or eclipsed, while the focus of attention shifts to the basic plan or formula (λόγος) of living systems. Like the history of Protestantism, the history of modern science is one of 'chronic iconoclasm' (Jung, 1954/1959a, p. 13). The programme of the life sciences of the twentieth century can be summarised as a systematic shift of focus: from form (εἶδος) to formula (λόγος), and from the organism as a whole (as a gestalt) to life as a legible code.

Deciphering the code (the elementary characters) of life (M_2, *object pole*)

The understanding of living beings as *realisations* of a molecular *programme* was elaborated by physicist Erwin Schrödinger in his science classic *What is Life?* (1944/1967). For

Schrödinger (a physicist), nature is under the sway of the entropy principle, unknown to Aristotle: the process of inevitable and relentless decay. Anything that is well-ordered is transient and bound to return to dust, to dissipate into the inorganic mayhem of molecular debris. Against the backdrop of an entropic world, the question emerges how something as complex, sophisticated and intricate as a living organism, or even a living cell, is able to maintain itself, with inconceivable persistency, and even to reproduce itself? What is it that enables cells to maintain their intricate form (εἶδος) over an extended period of time? In contrast to Aristotle, Schrödinger no longer sees the form as something which is inherently stable. The form is no longer a principle of stability in and by itself. Life, for Schrödinger, is 'negative entropy'. It is the remarkable ability to withstand the pervasive, disruptive natural tendency towards entropy, towards the relentless pulverisation of forms. How is this possible?

For Schrödinger, the answer is that life is possible because of the programme or code (Aristotle's λόγος), more precisely: the 'genom' (spelled without an *e* by Schrödinger), an 'aperiodic crystal' which carries a molecular 'Morse code', as Schrödinger phrases it, that allows living cells to keep themselves *in shape* and to maintain their astonishing complexity and homeostasis, and even to replicate themselves. This code consists of strands of letter-like elements or characters (Aristotle's γράμματα) which *realise* themselves in living organisms. In 1953, inspired by Schrödinger's vision, Watson and Crick were indeed able to uncover the basic molecular structure of this code, in the form of the nucleotide alphabet: the γράμματα A, C, G and T (Zwart, 2013). As realisations of their programme, living cells function, maintain their homeostasis and replicate themselves. And it is because of this logical programme that a human being, as a *logical* animal (ζῷον λόγον ἔχον) is able to discern and read this intelligible λόγος pervading living nature, albeit with the help of high-tech sequencing equipment.

In the course of the twentieth century, this research programme was completed more or less, culminating in genomics highlights, most notably the *Human Genome Project* (HGP). And now that the genomes of thousands of species have been sequenced, analysed, stored and published, we witness another dialectical turn. Another *enantiodromia* is setting in, as Jung phrases it (1954/1959c, p. 346, 348), namely the shift from analysis to re-synthesis, from reading to rewriting, from reductionism to holism and reintegration (Moya et al., 2008; Zwart, 2012), in short: from genomics to synthetic biology. In order to understand how cells operate, techno-science initially tried to analyse and dismantle them, thus disclosing the basic molecular components, i.e. molecular 'matter' (the molecular life sciences version of Aristotle's ὕλη), governed by a logical programme (λόγος), by the strands of symbols that orchestrate the functioning and self-replication of cells. But how can we know that this process of analysis is really completed? The idea is that we only know that we really understand how a living cell functions if we can *realise* this programme ourselves, *in vitro* this time, namely by producing a synthetic cell bottom-up, starting from the biomolecular components (Carrera & Covert, 2015; Russel et al., 2012). The development of synthetic cells (also known as artificial cells or protocells) is expected to 'illuminate the perennial question "What is life?"' (Rasmussen et al., 2017). According to Murtas (2009) and others, the construction of such cells has now become a feasible option. Synthetic Biology offers the technologies to build a synthetic cell, bottom-up indeed, by re-synthesising 'all the essential biochemical mechanisms to yield a functionally and structurally understood self-replicating biosystem' (Murtas, 2009, p. 1292). Such a project will

produce a 'deep understanding' of cellular processes and mechanisms. Porcar et al. (2011), likewise, argue that advances in DNA synthesis, in combination with a better understanding of regulatory processes, make the goal of constructing artificial cells a realistic possibility. Indeed, they consider the construction of artificial life as one of the main scientific challenges of the synthetic biology era (cf. Tomita, 2001).

Thus, the BaSyc project aims to address Schrödinger's basic question 'What is life?' As Max Delbrück (1971), the founding father of molecular life sciences argued, contemporary life sciences research adheres to an Aristotelean view of life. The form (phenotype) of living beings is determined by a programme (genotype) that *realises* itself in a living organism. This neo-Aristotelean view of life now evolves into synthetic biology: the effort to build artificial systems that mimic biological cells, where our knowledge concerning the elementary building blocks and codes of life is complemented with a desire for a return to the (obliterated) whole. And in order to visualise the abstract logic of this process, technoscientific discourse reverts to the use of images.

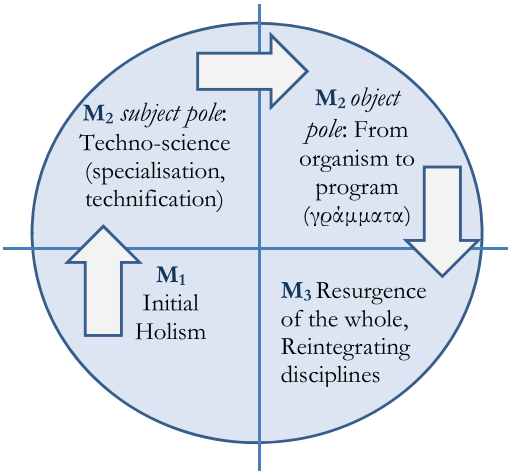
Even the word 'cell' is an image, by the way, introduced by Robert Hooke during the dawn of the modern scientific revolution, in his science classic *Micrographia* (1665). The cork cells which he spotted through his microscope reminded him of monks' cells in a monastery. Thus, notwithstanding the iconoclastic tendency at work in scientific research, scientific discourse is replete with images, as products of imaginative thinking.

The advent of a scientific mandala (M_3)

In recent technoscientific efforts to visualise synthetic cells, one particular image is especially striking, namely the mandala image: the tendency to represent synthetic cells (inexistent as yet) with the help of mandala-like, circular-quadratic diagrams, with a nucleus and a protective membrane, suggesting wholeness and completion. Like all archetypes, the mandala archetype is an a priori, formal, 'crystalline' structure, a ground plan which can be developed and elaborated in various ways (Jung, 1954/1959b, p. 79). As Carl Gustav Jung argued, the mandala archetype will often function as a compensation for the disruptive, fragmented and 'chaordic' features of the actual situation (Jung, 1944/1968, p. 27). Besides being a symbol of healing and wholeness, moreover, it may also provide a visual aid or roadmap for researchers involved.

In the remainder of this article, I will assess examples of synthetic biological mandalas from a Jungian perspective, as a product of active imagination and as an actualisation of the archetype of recovered wholeness and completion. Not only in the sense that the synthetic cell would be the fulfilment of a long and eventful history (a journey of discovery that began with the discovery of the molecular structure of DNA in 1953), but also in the sense that this type of research may actually be regarded as a practice of the self, fostering what Jung refers to as 'individuation'. At the same time, the mandala as a symbol of unity and wholeness may obfuscate instances of disruption, tension and conflict actually emerging in the context of laboratory life.

From a Jungian perspective, the current situation in contemporary technoscience (more specifically: in synthetic biology) can be represented with the help of a circular quadrant:



The shift away (first arrow) from the organism as a whole (from initial holism, M_1) towards specialisation and technification (M_2, *subject pole*), resulting in the systematic and relentless dissection, molecularisation, symbolisation and obliteration of life (second arrow), reflects the chronic iconoclasm of modern science. In the course of this process, the living organism becomes replaced by strands of code (γράμματα) that can be analysed and manipulated on computer screens (M_2, *object pole*). The logos-dimension of living systems is referred to as the 'Morse code' (Schrödinger) or 'barcode' or 'language' of life (Collins, 2011).[6] The genome as the programme (in the sense of computer programme) is a well-known bio-scientific metaphor, borrowed from computer research and introduced into biology, in other words, transferred from the technical into the natural, from *in silico* to *in vivo*. Whereas the word *cell* already conveys a powerful image (transferred from monastic architecture into biology, as we have seen), the *synthetic* cell has been referred to as the holy grail of synthetic biology (Bedau, 2007), a symbol of ultimate wholeness (the telos of individuation) and of the self, imported from alchemy and Christian mysticism.

In this contribution, however, I will focus on another archetypal form emerging in synthetic biology discourse and playing a key role in Jung's oeuvre, namely the synthetic cell as the mandala of contemporary life sciences research. The association with mandalas easily comes to mind whenever we are exposed to model versions of synthetic cells, as diagrams in research papers, for instance, or displayed on PowerPoint slides during meetings and conferences. In the next section, building on the work of Jung, I will explore the relevance of this archetypal structure, borrowed from the spiritual realm, to deepen our understanding of the meaning of the synthetic cell endeavour.

Life sciences mandalas (amplification)

A mandala, Sanskrit for circle (more specifically: sacred circle), is a spherical-quadratic diagram, a harmonious, symmetric image, a pattern of geometric shapes, contained within a circle or square (or squared circle), concentrically arranged and radiating from a centre. According to Jung, it is an archetypal symbol for unity or wholeness (1944/1968, p. 27; 1950/1959, p. 356) and constructed through active imagination (1944/1968,

p. 96; 1950/1959, p. 356). It depicts a 'squaring of the circle', containing everything and revealing how everything is related (1950/1959, p. 357). It may be the ground-plan for a building (a garden, a temple, a monastery courtyard, a city). The ground-plan for the Pantheon in Rome, for instance (Figure 1), can be considered a mandala: a spherical building containing *everything* (everything spiritual, for *pan-theon* means 'all the gods').

A mandala is often used as a 'yantra' (an instrument or visual aid employed in contemplative and meditative exercises), a contraption that narrows down the psychic field of vision (Jung, 1950/1959, p. 356). But it may also serve as a roadmap or guide for processes of healing, reconciliation, reintegration and individuation. By realising wholeness, a mandala compensates for the contradictions, conflicts and disorderliness of actual reality (Jung, 1944/1968, p. 27; 1950/1959, p. 388). A mandala reflects and enables the transition from disorientation and confusion to order, balance and wholeness (Jung, 1950/1959, p. 360). The centre has special relevance and may contain a symbol, a sacred text or a healing substance (φάρμακον). A mandala is a *coniunctio oppositorum* (a union of opposites), for instance: light and darkness, a circle and a square (cf. the Pantheon), but it is also a conjunction of the rational and the spiritual, of the symbolical and the imaginary (or, in the case of the Pantheon, of the theological and the political). It is a symmetrical arrangement of seemingly contradictory and irreconcilable elements (1950/1959, 388). As the archetype of cosmic wholeness, mandalas often suggest the shape of an eye or an egg. A mandala represents integration and homeostasis, but it may also be seen as the map or programme for a long and difficult journey, with each layer representing a part of this journey (towards wholeness or individuation).

What is the connection between mandalas and modern science? First of all, Jung commenced his systematic analysis of mandalas in order to understand the dreams of a famous scientist who also was a prolific dreamer (one of the most famous dreamers in

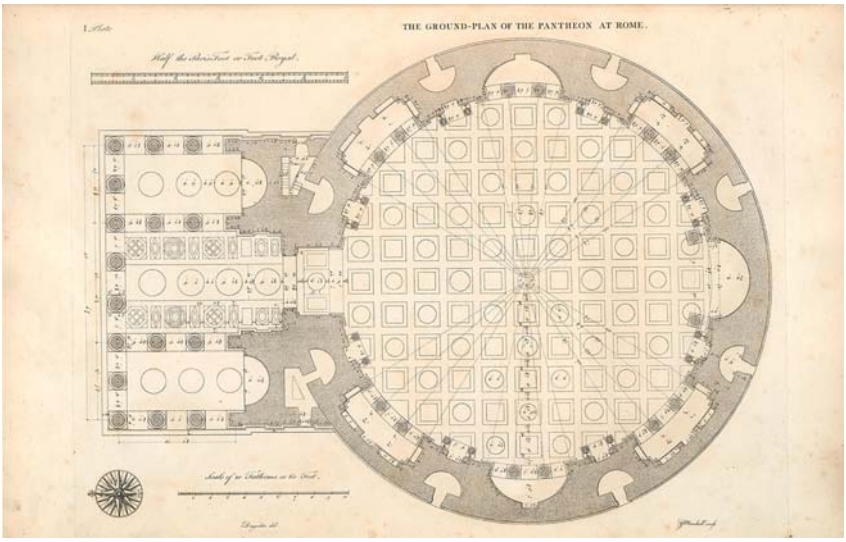


Figure 1. Ground-plan of the Pantheon.

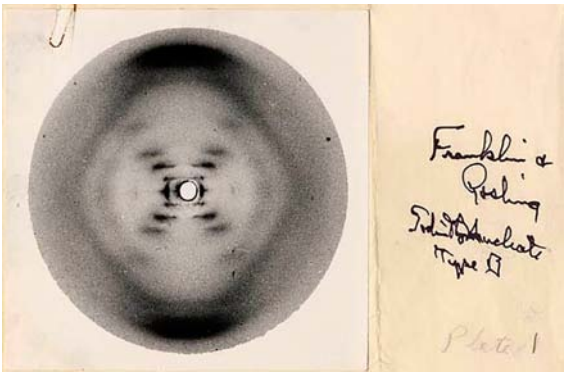


Figure 2. Photograph 51 (X-ray diffraction image of DNA).

the history of dream analysis in fact), namely Nobel laureate Wolfgang Pauli (Jung, 1944/1968, p. 42; Lindorff, 1995, 2004), a prominent quantum physicist who, among other things, postulated the existence of the neutrino in 1930 and acted as Mephistopheles in the famous Copenhagen version of Goethe's Faust, written by Max Delbrück and performed in 1932 (Gamow, 1966; Segre, 2008). According to Jung, mandalas played an important role in Pauli's dreamlife, perhaps to compensate for the disruptive impact of quantum physics on established worldviews.

But there are more mandalas showing up in modern science. One important example is the famous photograph 51 (Figure 2), taken by Rosalind Franklin and her collaborator Raymond Gosling in 1952 and shown by Maurice Wilkins (without Franklin's knowledge) to James Watson (in a corridor at King's College, London) as a decisive piece of evidence for the helical structure of DNA: a crucial step on the pathway that led to the unveiling of DNA (Zwart, 2015). This photograph (a helical structure, seen from above) reflects the archetypal structure of a mandala, which is no coincidence of course, for this picture marks a crucial milestone in a long and complicated project (focussed on understanding the noumenal, molecular essence of life), of which the synthetic cell would be the final completion (the Omega point).

Or take the first completed sequence of a cellular genome: of the bacterium *Haemophilus influenza*, proudly presented in 1995 by J. Craig Venter and his team (Figure 3). In the circular representation of the bacterial genome, the mandala archetype can be discerned. And indeed, in countless visualisations of biological structures, presented on PowerPoints during academic lectures for instance, or available on the Internet, the archetypal features of mandalas can be pointed out. But what could be the philosophical benefit of such exercises in pattern recognition?

From the point of view of scientific iconoclasm, there may even be epistemic risks involved in this technoscientific predilection for mandala-like imagery. As Conti, Valerio, Zbilut, and Giuliani (2007) argue, for instance, scientists often try to create a semblance of order in the messy materials coming from -omics experiments by translating the complicated input into graph-like structures, with genes, protein, metabolites and their various interactions represented with the help of nodes and arrows. But although 'scientists are in general very fond of these Mandala-like pictures' (Conti et al., 2007, p. 164), such

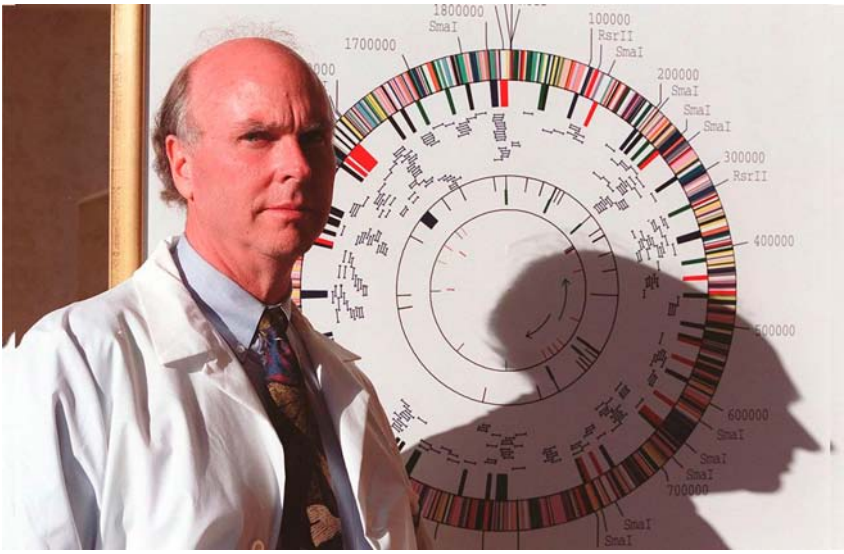


Figure 3. J. Graig Venter posing before the gene map of Haemophilus influenza (1995).

visualisations may prove arbitrary and ad hoc, and the suggestion of transparency may actually be misguiding, for there is always *much more* to such 'chaordic' living systems (Hock, 1999) than what is captured by quasi-reassuring and simplifying diagrams.

Although (from the point of view of iconoclasm) caution or even suspicion concerning the use of mandalas seems recommendable, they continue to pop up in technoscientific discourse. Below, a sample of scientific mandalas is presented, taken from various sources discussing synthetic cells, in a more or less random fashion, for the scientific literature on synthetic cells abounds in such mandala-like diagrams. Figure 4 depicts an 'artificial cell-based device' discussed by Giovanni Murtas (2009); Figure 5 represents a 'strategy for whole-genome synthesis' presented by Hutchison et al. (2016); Figure 6 is a cover of the journal *Systems and Synthetic Biology*, available on the journal's website;[7] Figure 7 is a protocell designed to mimic a biological cell (discussed by Kamat, Katz, & Hammer, 2011); and Figure 8 was taken from the website of the *Synthetic Biology Foundry*.[8] Finally, Figure 9 is a cover of the journal *Nature Arabic* (which, although not specifically referring to synthetic biology discourse, I added because of symbolical reverberations).[9]

As to the technical details connected with these visuals, the sources as indicated can be consulted, but I look at these diagrams from an 'oblique' perspective (Zwart, 2017a). For rather than on the technoscientific details of any of these diagrams in particular, a depth psychological perspective will consider the overall picture, with evenly poised attention as it were, focussing on the basic, archetypal structure that is visible in the way in which these images are constructed and presented. Why do discussions concerning synthetic cells generate such mandala-like images?

First of all, as we have seen, a mandala is an archetype of wholeness, and the synthetic cell can be regarded as symptomatic for the resurgence of holism, the return of the

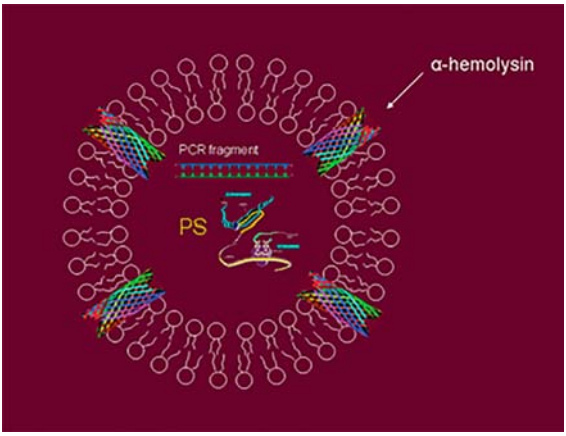


Figure 4. Artificial cell-based device.

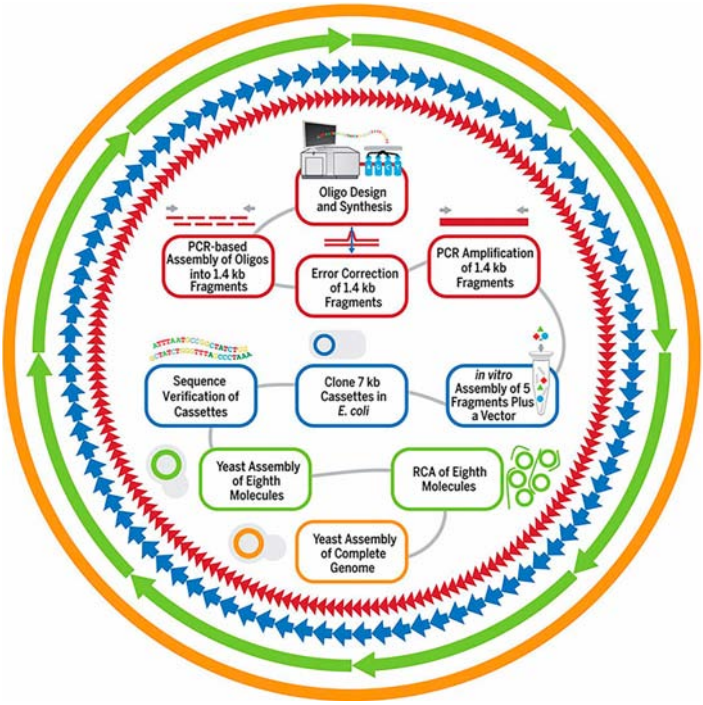


Figure 5. Strategy for whole-genome synthesis.

rediscovered whole: the *third moment* (M_3) in the dialectical schema of science outlined above. The synthetic cell is a bio-molecular microcosm, a structure containing and assembling 'everything', i.e. everything that is currently known about the biochemical structures

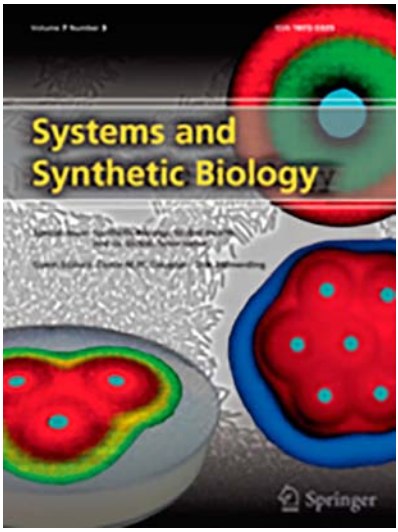


Figure 6. Journal cover of *Systems and Synthetic Biology*.

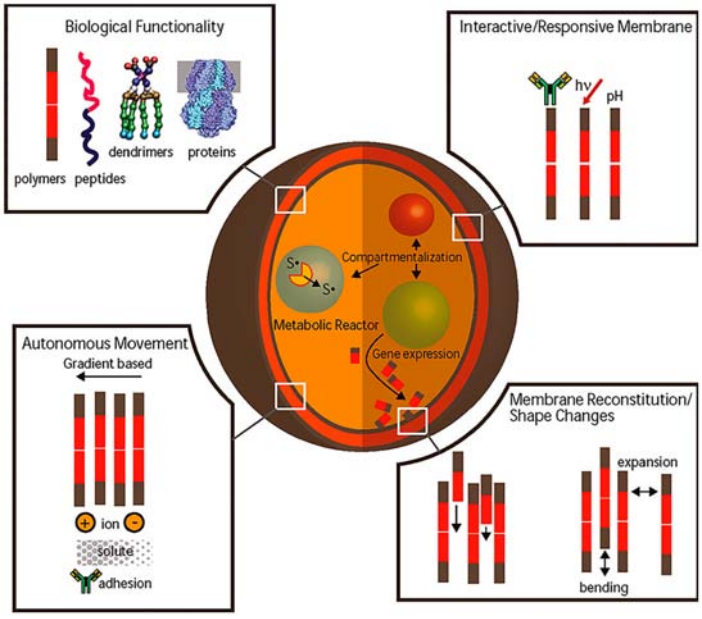


Figure 7. Protocell designed to mimic a biological cell.

and processes of cellular life, while indicating how all these processes and components may be interconnected. And while the cell membrane acts as the protective circle, the nucleus is the symbolic centre (from where molecular messages radiate into the spherical

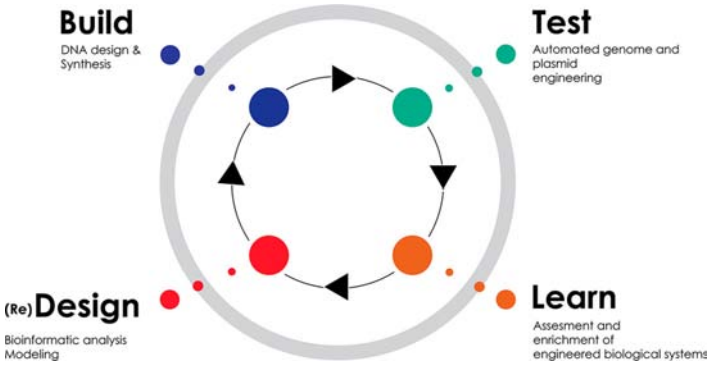


Figure 8. Photo taken from the website of the *Synthetic Biology Foundry*.

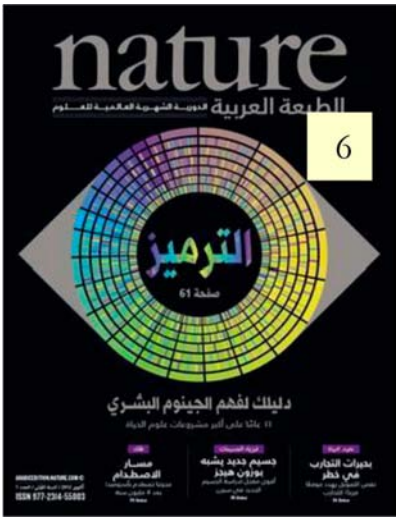


Figure 9. Journal cover of *Nature Arabic*.

whole). A mandala-like diagram may represent the basic ground-plan or 'architecture' (Rafelski & Marshall, 2009) of a synthetic cell, but it may also be regarded as a visual aid or roadmap for the process of actually building such a cell. In the course of the twentieth century, living cells were broken down into elementary molecular components, as we have seen, represented with the help of alphabets of bio-scientific characters (γράμματα), referring to basic building blocks of life (nucleotides, genes, amino acids, proteins, etc.). The objective of building a synthetic cell is to bring all these components together again. Therefore, synthetic biology is regarded as 'holistic', even by authors who confess to being troubled by the 'esoteric' connotations of the term (Conti et al., 2007, p. 161).

From a depth psychology perspective, the building of a synthetic cell is an exercise in reparation as it were. All the partial objects of research projects of the past are granted a

functional place within the synthetic cell as a holistic, all-encompassing, pantheon-like assembly. As a scientific model or structure, it is evidence-based, but at the same time imaginative, and the synthetic cell emerges gradually, step by step, guided by (active) imagination as it were. The centre consists of the nucleus containing the programme (λόγος) of the cell, the core concept which realises itself in the visible, functioning assembly. What is also interesting is that these mandala-like representations mimic the basic (egg-like) form (εἶδος) of a biological cell, while at the same time visualising the building-plan or programme (λόγος). Although a synthetic cell will perhaps not be a realistic replica of a living biological cell, it presents the general outline or model, the overall idea (εἶδος). The synthetic cell mandala reflects the archetypal, egg-like form, thus constituting a high-tech version of the 'Orphic egg',[10] symbolising the beginning and essence of life (Jung, 1954/1959a, p. 293). The mandala structure exemplifies balance and homeostasis, moreover: the equilibrium of multiple counteracting and apparently incompatible forces (*coniunctio oppositorum*). By reflecting the archetypal form (εἶδος) of a mandala, a synthetic cell diagram may also serve as a visual aid helping researchers to synthesise the various biochemical, biomolecular and bio-computational fragments into a comprehensive whole, comparable to how the double helix structure provided a structural scaffold allowing Watson and Crick to build their model version of DNA. Thus, the synthetic cell symbolises the resurgence of the form (εἶδος), or rather, it realises a reintegration, reconciliation or synthesis of the *form* (εἶδος) and the *formula* (λόγος) of a cell, but now in vitro.

Still, this is only half of the story, focussing on the object pole (the end product of the endeavour). The correspondences between synthetic cell diagrams and mandalas also pertain to the subject pole, however (i.e. the researchers or research teams involved). As a psychologist, Jung was focussed on the scientific subject, rather than on the scientific object. He was more interested in Wolfgang Pauli as a (tormented) person than in neutrinos, so to speak, notwithstanding the fact that Pauli's intriguing case history was of course intimately connected with this elusive, almost mass-less object (the most bizarre perhaps of all the elementary particles of quantum physics). As a concretisation of the mandala archetype, the synthetic cell concept plays a role in the process of individuation. Synthetic biology research (the reintegration of scientific sub-disciplines and specialities into a comprehensive programme, a *Gesamtwissenschaft*) becomes a practice of the self. Whereas in the past researchers and research teams were working under the sway of specialisation, focussing on partial objects (on very specific molecules or molecular processes for instance), the synthetic cell (reflecting the holistic turn in contemporary life sciences research) allows for convergence, also in terms of the research programmes and research activities involved. After decades of reductionism and fragmentation, researchers are now again envisioning the cell *as a whole*. It is only by reintegrating this microcosmic *whole* that a cell can be truly understood.

Individuation: restoring the whole

The cell is a microcosm, a condensation of living nature as such, and the synthetic or holistic turn in biology concurs with a process of integration on the part of the scientific subjects themselves. Synthetic cell projects such as BaSyC assemble experts representing multiple disciplines and approaches, so that the synthetic cell becomes a kind of scientific *Gesamtkunstwerk*, actively engaging a significant sample of contemporary technosciences. The basic logic of such a programme still resounds with Schrödinger's argument that, in

order to elucidate the enigma of life, biologists and physicists should learn to collaborate. The disruptive impact of elementary particles physics and elementary particles biology (i.e. molecular life sciences research) is now sublated into the synthetic cell as a form of closure. At the same time, the synthetic cell mandala represents a kind of map, guiding the researchers involved on their journey to these new insights, turning research into self-edification, so that the building of a synthetic cell entails an element of Self-*Bildung* as well.

Thus, the synthetic cell mandala indicates how, within this closure, all parts and processes are interconnected, but the ultimate test to see whether the synthetic cell project has achieved its goal is passed when the technologically reproducible cell is able to replicate itself. This is another feature which the synthetic cell shares with the mandala archetype: the tendency to duplicate itself and to split up into two identical or slightly different halves, in psychotherapy as well as in laboratory research (Jung, 1954/1959a, p. 344).

From a Jungian perspective, moreover, synthetic cell mandalas must be seen as compensations for current deficits. In terms of diagnostics, the present state of research in synthetic biology can be considered as 'chaordic' (Conti et al., 2007; Hock, 1999). The mandala signifies an ideal end state of convergence, an Omega point as it were. While the synthetic cell mandala symbolises the inviting future, in existing laboratories researchers are still challenged by multiple conflicts, tensions and frustrations. The synthetic cell mandala functions as a psychic aid, guiding researchers in their efforts to face the realities of laboratory life, for instance in terms of competitive tensions and perverse incentives (and their adverse impacts on the individuals involved). In the nineteenth century, scientists working in laboratories (due to their exposure to toxic substances and other unhealthy conditions) often developed a typical, professional psychopathology referred to as *hysteria chemicorum* by Justus von Liebig (one of the founding fathers of modern organic chemistry) in a letter to his ailing friend and colleague Friedrich Wöhler (Ostwald, 1909, p. 180; Zwart, 2017b, p. 161). And although contemporary laboratories tend to be much cleaner as physical environments, the mental challenges of laboratory life (in terms of competition, time pressures, conflicting expectations, career uncertainties, etc.) may prove challenging enough, so that mandala-like representations of common objectives may be expected to compensate these disruptive tendencies. In other words, as a visual representation of a common goal or ideal, life sciences mandalas (presented in bright colours during lectures, for instance) may have a performative effect, fostering team building and acting as a source of consolation or inspiration.

Yet, from a Jungian perspective, the mandala archetype also represents a danger, namely that of succumbing to the fascinating power of the primordial image (1954/1959a, p. 39), so that actual tensions and frustrations are obfuscated rather than addressed. This danger can only be averted by becoming conscious of the archetype at work, by coming to terms with it, in the context of a dialectical procedure (p. 40). Thus, the archetype may allow researchers to consciously *integrate* the precision knowledge provided by contemporary technoscience into the integral structure of the mandala, so that research becomes a practice of the self. Mandalas may function as visual aids or symbolic scaffolds for achieving individuation, on the condition that the imaginative power of the mandala structure is brought to the surface and actively employed, as a tool of active imagination, resulting in a reconciliation of the imaginary and the symbolical (of the φαντάσματα and the γράμματα).

Although the current technoscientific drive to reconstructing life has been compared to alchemy before (Kirkham, 2009; Nicholls, 2004), a Jungian analysis allows us to make

this type of comparison more specific and precise, with the help of key concepts such as the mandala archetype. The synthetic cell mandala can be regarded as a dialectical blending of bio-molecular knowledge with active imagination, as we have seen. As a symbol of restored unity, it compensates for technoscientific fragmentation and provides a visual aid or roadmap for the reintegration work. The archetypal idea of an all-encompassing (spherical or egg-shaped) vessel, functioning as a microcosm, provides a symbolic scaffold which allows scientists to put the various partial components and processes together again. The synthetic cell as an archetypal vessel for reintegration (*vas* in Latin, κρᾶτήρ in Greek) is projected onto biomolecular matter, and projected into the future. Thus, the synthetic cell project becomes a contemporary technoscientific version of the *opus alchemicum*, which implies that integration emerges on both sides of the equation, both at the subject pole and at the object pole: *tam ethice quam physice*, as Jung phrases it (1944/1968, p. 243). For indeed: a similar process of convergence and transdisciplinary integration can be discerned at the subject pole as well. Now that the *spirit* hidden in matter (i.e. biomolecular information, the programme that creates order in entropic molecular dust) has been brought to the fore, has been articulated in technoscientific discourse, it may now be brought in conjunction with biomolecular *matter* again, albeit on a higher level of self-consciousness and transparency. And active imagination, with colourful technoscientific diagrams, contributes to this process, which is a technoscientific revival of the *opus*, and, therefore, an end in itself (a panacea), so that potentially useful discoveries (new pharmaceuticals for instance) are merely seen 'by-products' (Jung 1944/1968, p. 241).

So far, we have focussed on the role of synthetic cell mandalas in research and concluded that mandala-like diagrams may play a performative role, as archetypal images suggesting wholeness, as symbolic scaffolds suggesting a future state of convergence. But this role of the mandala archetype namely to compensate for current tensions and conflicts in actual research practices, not only applies to the research arena as such. Mandalas may also suggest a possible sublation of conflicts and tensions arising between science and the wider socio-cultural environment. Take for instance the SIS-RRI project (short for *Science, Innovation and Society: achieving Responsible Research and Innovation*), a H2020 project funded by the European Commission during the period 2014–2015. Below, the mandala-like visual of a conference organised by the SIS-RRI project is inserted.

Again, I would argue that the mandala archetype works as a symbol here, a symbolic scaffold, suggesting a future situation of wholeness. Such images serve as a visual aid, a source of inspiration for working towards overcoming the science-society divide by bringing together (into one diagram) various aspects that tend to remain compartmentalised in the current situation: basic and applied research, research and education (both primary and advanced), but also research and societal debate. This alluring prospect (the convergence of such apparently incompatible components) compensates for current tensions. The suggestion is that all these seemingly diverging elements can indeed be brought together in a *coniunctio oppositorum* (in bright colours) represented by a figure which, not coincidentally, is mandala-shaped. In this manner, the connection with the archetype can be re-established.

Once again, moreover, also in this case the mandala archetype suggests that the process of individuation should not restrict itself to laboratory life, but should encompass societal responsibility as well. Individuation requires sublation of the science-society divide, both on the individual and on the collective level, via laboratory research and societal debate, as complementary practices of the self.

One may wonder of course whether things like societal deliberation and education (represented in this optimistic, mandala-style visual) can really bring this about. As Jung argues, the iconoclastic waves unleashed by Protestantism, Enlightenment and modern science resulted in a massive twilight of the archetypes, of the 'protective wall of sacred images', 1954/1959a, p. 14). In the aftermath of this socio-cultural cataclysm, mandala-like visuals (such as the one depicted above) seem impoverished secular substitutes for an obfuscated spirituality. Jung would probably discard RRI as one of those social ideas meant to 'fill the vacuum', but tainted by 'spiritual bleakness' (1954/1959a, p. 15). The problem of archetypal images (and of the imaginary as such) is that these alluring prospects may underestimate and obfuscate (rather than address and overcome) the deficiencies and fragmentation of the current situation. As a soothing symbol of hope, it may foster optimism and imagination, but it may also cover up conflicts of interests and other societal complexities: erecting an alluring but misleading façade, instead of fostering an authentic process of working through.

The latter can only be brought about if the synthetic cell endeavour (exemplified by the BaSyC project as a case history so to speak) really evolves into a high-tech, post-millennial version of the *opus alchymicum*, i.e. science as a *Gesamtwissenschaft*, providing a scaffold for individuation. As Jung argued, 'the tempo of the development of consciousness through science and technology was too rapid and left the unconscious, which could no longer keep up with it, far behind, thereby forcing it into a defensive position' (p. 349). The mandala archetype is a scaffold which allows researchers to reconnect with the unconscious, edifying the self at the subject pole, while rehabilitating the whole at the object pole. In other words, the synthetic cell project becomes a work of epistemic therapy. The down-side, however, is that all this may easily remain a superficial and imaginary endeavour, so that the brightly coloured mandalas appearing in scientific lecture halls merely serve as a façade, obfuscating a lack of real commitment, a readiness to *durcharbeiten* (scientific work as *working through*).

Notes

1. https://www.nwo.nl/en/research-and-results/research-projects/i/45/29045.html

2. A similar distinction (a similar dialectics) can be encountered in the work of psychoanalyst Jacques Lacan, namely as the distinction between the *imaginary* (focussed on images or φαντάσματα) and the *symbolic* (focussed on symbols or γράμματα).
3. Cf. 'Whereas the comparative anatomy or morphology of animals and plants, based on collection, observation, comparison, and description, was the definitive technique for the classification of life forms during the classical period of natural history, it is molecular biology that today provides the primary analytic perspective on the essence of life and its defining mechanisms … What is considered to be 'the stuff of life' in modern scientific terms [i.e. DNA, composed of nucleotide chains that guide the manufacture of essential proteins, that all living beings are now known to have in common] is today more similar to biochemistry than to zoology' (Franklin, 1995/2014, p. 1811).
4. 'Jeder Stern am Himmel ist ein geistiges Gewächs, dem ein Kraut bei uns auf Erde entspricht, und jener zieht durch seine anziehende Kraft das ihm entsprechende Kraut auf der Erde an, und jedes Kraut ist daher ein irdischer Stern und wächst über sich dem Himmel zu' (1853, p. 205).
5. For instance: 'Nous allons réunir et compléter les observations de C.G. Jung' (Bachelard, 1938/1949, p. 43); 'Jung découvre dans les images de l'alchimie l'action des archétypes de l'inconscient' (Bachelard, 1948, p. 5); 'Nous emprunterons alors la plupart de nos arguments à la psychologie des profondeurs. Dans des nombreuses œuvres, C. G. Jung a montré l'existence d'une dualité profonde de la psychè humaine' (Bachelard, 1960, p. 17); etc.
6. In Lacanian terms, this is the 'symbolisation' of the real, the obfuscation of the imaginary by the symbolical.
7. https://link.springer.com/journal/11693
8. http://syncti.org/research/synthetic-biology-foundry/
9. https://arabicedition.nature.com/
10. In the Ancient Greek Orphic tradition, the Orphic egg is the cosmic egg which gave birth to the primordial hermaphroditic deity Phanes, also equated with Pan.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by Netherlands Organisation for Scientific Research [grant number 024.0003.019].

Notes on contributor

Prof. Dr. H. A. E. (Hub) Zwart (1960) studied Philosophy and Psychology at Radboud University Nijmegen (The Netherlands). In 2000 he was appointed as full professor of philosophy at the Faculty of Science (RU Nijmegen). In 2003, he became director of the Centre for Society and Genomics (CSG) and in 2005, Director of the Institute for Science in Society. His research focuses on philosophical dimensions of the biosciences (synthetic biology, nanomedicine, brain research) which are addressed from a continental philosophical perspective (dialectics, phenomenology, psychoanalysis) while special attention is given to genres of the imagination (novels, theatre, poetry, movies) as windows into emerging techno-scientific research fields.

ORCID

H. A. E. (Hub) Zwart http://orcid.org/0000-0001-8846-5213

References

Aristotle. (1965). *History of animals I-III* (Loeb). Cambridge: Harvard University Press.

Aristotle. (1986). *De Anima/On the Soul* (Loeb). Cambridge/London: Harvard University Press/ Heinemann.

Bachelard, G. (1938/1949). *La psychanalyse du feu*. Paris: Gallimard.

Bachelard, G. (1947). *La formation de l'esprit scientifique: Contribution à une psychanalyse de la connaissance objective*. Paris: Vrin.

Bachelard, G. (1948). *La terre et les rêveries de la volonté*. Paris: Corti.

Bachelard, G. (1953). *Le matérialisme rationnel*. Paris: Presses Universitaires de France.

Bachelard, G. (1960). *La poétique de la rêverie*. Paris: Presses Universitaires de France.

Bedau, M. (2007). Artificial life. In M. Matthen & C. Stephens (Eds.), *Philosophy of Biology (Handbook of the Philosophy of Science)* (pp. 585–603). Amsterdam: Elsevier.

Bratranek, F. T. (1853). *Beiträge zu einer Ästhetik der Pflanzenwelt*. Leipzig: Brockhaus.

Carrera, J., & Covert, M. W. (2015). Why build whole-cell models? *Trends in Cell Biology*, *25*, 719–722.

Collins, F. (2011). *The language of life: DNA and the revolution in personalised medicine*. New York, NY: Harper.

Conti, F., Valerio, M. V., Zbilut, J. P., & Giuliani, A. (2007). Will systems biology offer new holistic paradigms to life sciences? *Systems and Synthetic Biology*, *1*, 161–165. doi:10.1007/s11693-008-9016-1

Delbrück, M. (1971). "Aristotle-totle-totle". In J. Monod & E. Borek (Eds.), *Of microbes and life* (pp. 50–55). New York, NY: Columbia University Press.

Franklin, S. (1995/2014). Life. In W. Reich (Ed.), *Encyclopaedia of bioethics* (pp. 1809–1817). New York, NY: Macmillan.

Gamow, G. (1966). *Thirty years that shook physics: The story of quantum theory*. New York, NY: Dover.

Goethe, J. W. (1817/1824). *Zur Naturwissenschaft überhaupt, besonders zur Morphologie*. Stuttgart: Cotta.

Hegel, G. W. F. (1807/1973). *Phänomenologie des Geistes*. Werke III. Frankfurt am Main: Suhrkamp.

Hock, D. (1999). *Birth of the chaordic age*. San Francisco, CA: Berret-Kochler.

Hooke, R. (1665). *Micrographia: or, Some physiological descriptions of minute bodies made by magnifying glasses*. London: Martyn & Allestry.

Huskinson, L. (2013). Housing complexes: Redesigning the house of psyche in light of a curious mistranslation of C. G. Jung appropriated by Gaston Bachelard. *International Journal of Jungian Studies*, *5*(1), 64–80.

Hutchison, C. A., Chuang, R.-Y., Noskov, V. N., Assad-Garcia, N., Deerinck, T. J., Ellisman, M. H., … Venter, J. C. (2016). Design and synthesis of a minimal bacterial genome. *Science*, *351*, aad6253. doi:10.1126/science.aad6253

Jung, C. G. (1911/1968). *Symbols of transformation: Collected works 5*. London: Routledge & Kegan Paul.

Jung, C. G. (1944/1968). *Psychology and alchemy: Collected works 12*. London: Routledge & Kegan Paul.

Jung, C. G. (1950/1959). Concerning mandala symbolism. In *Archetypes and the collective unconscious: Collected works 9* (pp. 355–384). London: Routledge & Kegan Paul.

Jung, C. G. (1954/1959a). Archetypes of the collective unconscious. In *Archetypes and the collective unconscious: Collected works 9* (pp. 3–41). London: Routledge & Kegan Paul.

Jung, C. G. (1954/1959b). Psychological aspects of the mother archetype. In *Archetypes and the collective unconscious: Collected works 9* (pp. 75–110). London: Routledge & Kegan Paul.

Jung, C. G. (1954/1959c). A study in the process of individuation. In *Archetypes and the collective unconscious: Collected works 9* (pp. 290–354). London: Routledge & Kegan Paul.

Kamat, N., Katz, J. S., & Hammer, D. A. (2011). Engineering polymersome protocells. *Journal of Physical Chemistry Letters*, *2*, 1612–1623.

Kirkham, G. (2009). Is biotechnology the new alchemy? *Studies in History and Philosophy of Science*, *40*, 70–80. doi:10.1016/j.shpsa.2008.12.004.

Lindorff, D. (1995). One thousand dreams: The spiritual awakening of Wolfgang Pauli. *Journal of Analytical Psychology*, *40*(4), 497–522. doi:10.1111/j.1465-5922.1995.00555

Lindorff, D. (2004). *Pauli and Jung: The meeting of two great minds*. Wheaton: Quest Books.
Mendel, G. (1866/1913). *Versuche über Pflanzen-Hybriden*. In E. von Tschermak (Ed.), *Ostwald's Klassiker der exakten Wissenschaften 121* (pp. 47–53). Leipzig: Engelmann.
Moya, A., Gil, R., Latorre, A., Pereto, J., Garcil, M., & Cruz F. (2008). Toward minimal bacterial cells: evolution vs. design. *FEMS Microbiology Reviews*, *33*(2009), 225–235. doi:10.1111/j.1574-6976.2008.00151.x
Murtas, G. (2009) Artificial assembly of a minimal cell. *Molecular Biosystems*, *5*(11), 1292–1297. doi:10.1039/b906541e
Nicholls, H. (2004). Biotech is the new alchemy. *Drug Discovery Today*, *9*(3), 103. doi:10.1016/S1359-6446(03)02975-1
Ostwald, W. (1909). *Grosse Männer*. Leipzig: Akademische Gesellschaft.
Porcar, M., Danchin, A., De Lorenzo, V., Dos Santos, V., Krasnogor, N., Rasmussen, S., & Moya, A. (2011). The ten grand challenges of synthetic life. *Systems and Synthetic Biology*, *5*(1-2), 1–9.
Rafelski, S. M., & Marshall, W. F. (2009). Building the cell: Design principles of cellular architecture. *Nature Reviews Molecular Cell Biology*, *9*(8), 593–602.
Rasmussen, S., Chen, L., Deamer, D., Krakauer, D., Packard, N. H., Stadler, P. F., & Bedau, M. A. (2017). Transitions from nonliving to living matter. *Science*, *303*, 963–965.
Russel, D., Lasker, K., Webb, B., Velazquez-Muriel, J., Tjioe, E., Schneidman-Duhovny, D., et al. (2012). Putting the pieces together: Integrative modeling platform software for structure determination of macromolecular assemblies. *PLoS Biology*, *10*, e1001244.
Schrödinger, E. (1944/1967). *What is life? The physical aspect of the living cell/mind and matter*. London: Cambridge University Press.
Segre, G. (2008). *Faust in Copenhagen: A struggle for the soul of physics*. New York, NY: Penguin Putnam.
Tomita, M. (2001). Whole-cell simulation: A grand challenge of the 21st century. *Trends in Biotechnology*, *19*, 205–210.
Zwart, H. (2008). Pea stories: Why was Mendel's research ignored in 1866 and rediscovered in 1900? In *Understanding nature: Case studies in comparative epistemology* (pp. 197–232). Dordrecht: Springer.
Zwart, H. (2012). On decoding and rewriting genomes: A psychoanalytical reading of a scientific revolution. *Medicine, Healthcare and Philosophy: a European Journal*, *15*(3), 337–346.
Zwart, H. (2013). The genome as the biological unconscious – and the unconscious as the psychic 'genome': A psychoanalytical rereading of molecular genetics. *Cosmos and History: the Journal of Natural and Social Philosophy*, *9*(2), 198–222.
Zwart, H. (2015). The third man: Comparative analysis of a science autobiography and a cinema classic as windows into post-War life sciences research. *History and Philosophy of the Life Sciences*, *37*(4), 382–412. doi:10.1007/s40656-015-0080-z
Zwart, H. (2016). The obliteration of life: Depersonalisation and disembodiment in the terabyte age. *New Genetics and Society*, *35*(1), 69–89. doi:10.1080/14636778.2016.1143770
Zwart, H. (2017a). The oblique perspective: Philosophical diagnostics of contemporary life sciences research. *Life Sciences, Society & Policy*, *13*, 4. doi:10.1186/s40504-017-0047-9
Zwart, H. (2017b). *Tales of Research Misconduct: A Lacanian diagnostics of integrity challenges in sciences novels*. Library of Ethics and Applied Philosophy 36. Dordrecht: Springer. doi:10.1007/978-3-319-65554-3