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Waddington, Holmyard and Alchemy: Perspectives on the Epigenetic Landscape

Abstract

In 1923, Conrad Hal Waddington was in his final year at Clifton College, Bristol, UK, being taught chemistry by Dr. Eric John Holmyard. During this year, Waddington and Holmyard both wrote about alchemy, the former in an extended school essay and the latter in the journal *Nature*. Almost twenty years later, Holmyard and Waddington were instrumental in the formation of the journal *Endeavour* in 1942. Using recently discovered primary source materials and unpublished manuscripts, the influence of Holmyard and alchemy on the early development of Waddington's thinking is explored, including his subsequent attraction to Alfred North Whitehead's process philosophy and the impact on his epigenetic research.

Keywords: epigenetic landscape, Conrad Hal Waddington, Clifton College, Eric John Holmyard, Alfred North Whitehead, epigenotype, *Endeavour*

Introduction

ὁδὸς ἄνω κάτω μία καὶ ὀντή

*The path up and the path down is one and the same.*¹

Conrad Hal Waddington was a leading English embryologist, geneticist and evolutionist, most active from the 1930s to the 1950s. He is best remembered for his experimental work and his concept of the “epigenetic landscape.” He has been described as the “father” of epigenetics.² Waddington's work has been re-evaluated in recent years and his

¹ Heraclitus, as quoted in, Jonathan Barnes, *Early Greek Philosophy*, Penguin Classics (London: Penguin Books, 2001), p. 51.

² Denis Noble, “Conrad Waddington and the Origin of Epigenetics,” *Journal of Experimental Biology* 218, no. 6 (2015): 816–18.

very significant contribution to contemporary biology is now fully recognised. For example, John Slack described Waddington as the “last renaissance biologist,” and Jonathan Bard suggested that “most of his work and ideas have been incorporated into the solid foundation of [biological] knowledge,” without people recognising it as Waddington’s work.³

In 1923, Waddington was in his final year at Clifton College, being taught chemistry by Eric John Holmyard. Ingram has written extensively about the influence of Clifton College, a public secondary school in Bristol, South West England, on the lives of a number of scientists who eventually became Fellows of the Royal Society.⁴ Holmyard and Waddington met up again eighteen years later in 1941, collaborating on the nascent scientific

³ Scott F. Gilbert, “Diachronic Biology Meets Evo-Devo: C. H. Waddington’s Approach to Evolutionary Developmental Biology,” *American Zoologist* 40, no. 5 (2000): 729–37; Nobel, “Conrad Waddington” (ref. 2), John M. W. Slack, “Conrad Hal Waddington: The Last Renaissance Biologist?,” *Nature Reviews Genetics* 3, no. 11 (2002): 889–95; Robin Holliday, “Epigenetics: A Historical Overview,” *Epigenetics* 1, no. 2 (2006): 76–80; Jonathan B. L. Bard, “Waddington’s Legacy to Developmental and Theoretical Biology,” *Biological Theory* 3, no. 3 (2008): 188–97; Brian K. Hall, “EvoDevo Concepts in the Work of Waddington,” *Biological Theory* 3, no. 3 (2008): 198–203; Melinda Bonnie Fagan, “Waddington Redux: Models and Explanation in Stem Cell and Systems Biology,” *Biology & Philosophy* 27, no. 2 (2012): 179–213; Bernhard Horsthemke, “Waddington’s Epigenetic Landscape and Post-Darwinian Biology,” *BioEssays* 34, no. 8 (2012): 711–12; Brian K. Hall, “Waddington’s Legacy in Development and Evolution,” *American Zoologist* 32, no. 1 (1992): 113–22.

⁴ Neil R. Ingram, “‘All That You Can’t Leave Behind’,” *Notes and Records of the Royal Society of London* 57, no. 2 (2003): 177–84; Ingram, “Science at Clifton,” *Cliftonian* (March 2016), supplement.

journal, *Endeavour*, for which Holmyard was to be editor. Waddington's contribution to the first edition was a brief paper entitled "The Epigenotype" that summarised some of his current research. His paper was reprinted in February 2011 in the *International Journal of Epidemiology*. Gilbert, in an accompanying commentary, describes the paper as a "truly revolutionary view of biology."⁵

Waddington credited Clifton and Holmyard as significant influences in the development of this thinking, although the necessary evidence needed to appreciate this fully has not been available to biographers.⁶ My paper presents this evidence and considers the influence of Holmyard and Clifton College on the development of Waddington's thinking, focussing especially on the years from 1923 to 1942.

Recently discovered, the private notebook of Holmyard covering the years 1922 to 1924 has provided an important new source of evidence. When read in conjunction with a school essay written by Waddington on alchemy in his final year at Clifton College in 1923, it provides the basis for a unique insight into the cultural influences on the young Waddington before he matriculated at the University of Cambridge. Private correspondence between Holmyard and Clifton College also sheds new insights into the personal circumstances surrounding the formation of the journal *Endeavour*.

⁵ C. H. Waddington, "The Epigenotype," *Endeavour* 1, no. 1 (1942): 18–20; Waddington, "The Epigenotype," *International Journal of Epidemiology* 41 (2011): 10–13; Scott F. Gilbert, "Commentary: 'The Epigenotype' by C. H. Waddington," *International Journal of Epidemiology* 41, no. 1 (2011): 20–23.

⁶ C. H. Waddington, *Towards a Theoretical Biology: Sketches*, ed. C. H. Waddington (Edinburgh: Edinburgh University Press, 1968); Waddington, *The Evolution of an Evolutionist* (Edinburgh: Edinburgh University Press, 1975).

This paper argues that the rigorous intellectual training Waddington received at Clifton College, with its emphasis on a broad cultural curriculum gave him a lifelong interest in science, philosophy, metaphysics, and art, as well as an appetite for vigorous intellectual debate, which characterised his whole professional life. Moreover, his extended study of alchemy seeded in his imagination the key ideas of the world egg and the ouroboros, that would reappear recontextualised in the epigenetic landscape, his major conceptual legacy. Evidence drawn from Waddington's writings will suggest how this recontextualisation took place.

Holmyard and Clifton College (1919–1923)

When Waddington entered the sixth form (his final years of secondary school) at Clifton College in 1922–1923, the Head of Science, E. J. Holmyard, was busy planning a new Science School, which was opened in 1927.⁷ Brian Pippard described the new building as a “palace of science,” which facilitated the education of many influential scientists including physicist Nevil Mott, biochemist John Kendrew, and, much later, physicist Michael Cates.⁸

Holmyard established an international reputation as a scholar of Arabic alchemy. Fluent in French, German, and Arabic, Holmyard's recently discovered notebook contains neat, handwritten notes on alchemical manuscripts from the Bibliothèque Nationale in Paris,

⁷ Anonymous, “The New Science School at Clifton College,” *Nature* 119 (1927): 871–73.

⁸ Ingram, ““All That You Can't Leave Behind”” (ref. 4).

and on the Arabic alchemical works published by Berthelot.⁹ What is noticeable is the absence of any strikeouts (Fig. 1). Holmyard was evidently not a man to make mistakes.

Figure 1: an extract from Holmyard's personal notebook concerning Arabian influences on alchemy.

The notebook shows Holmyard preparing a challenge to Berthelot's assertion that the works attributed to the Arabic alchemist Jabir ibn Hayyan and the Latin works ascribed to Geber were by different authors.¹⁰ Holmyard presented evidence to assert that Jabir ibn Hayyan and Geber were the same person in several papers during 1922–1923, in *Nature and*

⁹ Marcellin Berthelot, *Histoire des Sciences: La Chimie Au Moyen Âge*, 3 vols. (Paris: Imprimerie Nationale, 1893).

¹⁰ E. J. Holmyard, "Material for the History of Arabian Chemistry," unpublished manuscript (c. 1925), Clifton College.

Science Progress.¹¹ Chapter 5 of Holmyard's popular paperback *Alchemy*, published just before his final illness provides an accessible account of the life of Jabir and of the controversy. Partington, in Holmyard's obituary in *Nature*, recognised that his "pioneering work has a permanent value" but cautioned that "recent research has shown that the problem of Jabir is very difficult and much remains to be cleared up."¹² The notebook also has extended passages of Arabic. Holmyard would later translate some of the papers of Jabir, for which he would receive the award of a D.Litt. degree from the University of Bristol in 1928. Holmyard was acquiring a collection of rare and important alchemical texts and manuscripts which have remained intact over the years at Clifton College. Holmyard let his "acolyte" work with these documents, for, as Waddington wryly observed, "he made me learn a smattering of Arabic and look at a large number of very odd late Hellenist documents."¹³

In 1923, Holmyard invited a practising Arabic alchemist to Clifton College to carry out experiments on the transmutation of lead and copper, using castor oil, honey, shellac, sulphur, mercury, oil of violets and "numerous elixirs unknown composition." Holmyard

¹¹ E. J. Holmyard, "Arabic Chemistry," *Nature* 109, no. 2746 (1922): 778–7; Holmyard, "Arabic Chemistry," *Science Progress in the Twentieth Century (1919–1933)* 17, no. 66 (1922b): 252–6; Holmyard, "Arabic Chemistry," *Nature* 110, no. 2765 (1922): 573–7; Holmyard, "The Emerald Table," *Nature* 112, no. 2815 (1923): 2; Holmyard, "Die Alchemie Des Geber," *Nature* 112, no. 2802 (1923): 50–5; Holmyard, "The Identity of Geber," *Nature* 111, no. 2780 (1923): 191–9; Holmyard, "Some Chemists of Islam," *Science Progress in the Twentieth Century (1919–1933)* 18, no. 69 (1923): 66–75.

¹² E. J. Holmyard, *Alchemy* (Harmondsworth: Penguin Books, 1957); J. R. Partington, "Dr. E. J. Holmyard," *Nature* 184 (1959): 1360.

¹³ Waddington, *The Evolution of an Evolutionist* (ref. 6).

reported that “unfortunately, the experiments were not a success; this the Shaikh attributed to the fact that our ‘fires’ (including the oxyhydrogen flame!) were not hot enough.”¹⁴

Holmyard was an accomplished practical chemist and a prolific author of chemistry textbooks. He taught Waddington chemistry during the summer holiday and the autumn term of 1922, “at least enough to push me into the lowest grade of assisted entry into the University, an Exhibition.” After that Holmyard could “break loose and teach me what he was interested in...the functions of the Alexandrian gnostics and the Arabian alchemists derived from them.”¹⁵ Edgar Jenkins wrote a brief biography of Holmyard and celebrates him as an “enthusiastic advocate” of the historical approach to chemistry teaching, which helped pupils to “learn how discoveries were made and, more particularly, to familiarise themselves with the ideas in the minds of the researchers, and to understand the methods by which they had overcome difficulties.”¹⁶

Such an approach is built on a deep scholarly interest in the origins of chemistry, in the ontogeny of matter and its metaphysical roots, as well as the epistemological development of chemical knowledge, derived from experimentation. From the outset, Waddington was trained to view science as having ontological, metaphysical, epistemological and empirical dimensions, and this became a foundation for all of his future work in science.

¹⁴ Ingram, “Science at Clifton” (ref. 4).

¹⁵ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 2.

¹⁶ Edgar W. Jenkins, “E. J. Holmyard and the Historical Approach to Science Teaching,” in *International Handbook of Research into History, Philosophy and Science Teaching*, ed. Michael R. Matthews (Dordrecht: Springer, 2014), pp. 2377–2408.

It is worth reflecting on the characters of the two men. Both were shy, reticent and aloof. Waddington was, in his own words an “unaggressive character.”¹⁷ Robertson says that he had “little or no small talk.”¹⁸ Holmyard was “unassuming and retiring...[who] rarely sought the company of his fellow men,” whereas Waddington readily sought the fellowship of like-minded people, and readily acknowledged their support and advice and “loved parties.”¹⁹

In 1929, Waddington submitted an essay entitled “Philosophy and Biology,” for the Arnold Gerstenberg prize at the University of Cambridge, for which he was awarded a scholarship.²⁰ It contains the generous and self-effacing acknowledgement:

But the name of [William] Bateson should be mentioned is that of a general influence. Apart from that, the atmosphere of ideas, which is found in places where numerous people are interested in similar things, is so pervasive that it is

¹⁷ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 10.

¹⁸ A. Robertson, “Conrad Hal Waddington, 8 November 1905–16 February 1975: Elected F.R.S 1947,” *Biographical Memoirs of Fellows of the Royal Society*, 23 (1977): 575-622, on p. 612.

¹⁹ Trevor I. Williams, “Holmyard, Eric John (1891–1959),” in *Oxford Dictionary of National Biography*, ed. Philip Carter and Aldwyn Roberts (Oxford University Press, 2004), accessed 17 April 2019 from <https://doi.org/10.1093/ref:odnb/33960>; Robertson, “Conrad Hal Waddington” (ref. 18), p. 612.

²⁰ C. H. Waddington, “Philosophy And Biology: Essay submitted for the Arnold Gerstenberg Prize, 1929” (typescript), Papers of Conrad Hal Waddington, Coll-41/2/1/2, Edinburgh University Library Special Collections, accessed 17 April 2019 from http://lac-archives-live.is.ed.ac.uk:8081/repositories/2/archival_objects/15408.

very doubtful whether I can claim even one of the smallest ideas in this essay as really and absolutely my own.²¹

Holmyard and Waddington were both fiercely rational men and could express blunt and strong opinions in print. For example, Waddington, putting forward a polemical claim that science should be at the heart of ethical and political questions, said: “[these claims] will probably be violently rejected by many most eminent and capable scientists; but I shall not be impressed by any rejection which does not seem to be based on substantial and rational grounds.”²²

Writing in the midst of the London blitz during World War II, Waddington despaired of the low opinion of science by educated people:

From being a matter of mundane “stinks,” unworthy of the attention of the man of letters, of the scholar, of the philosopher, of all whose business is to further the evolution of man’s soul, scientific thought has become the pattern for the creative activity of our age, our only mode of transport through the rough seas in front of us.²³

“Stinks” was the nickname that Clifton College pupils gave to chemistry in the 1920s and it is likely that Waddington was reflecting on his old chemistry teacher, who was an eminent man of letters, a scholar, a philosopher, who did so much to further the evolution of Waddington’s soul, by revealing a pattern for the creative activity of his professional life.

Holmyard’s influence on Waddington was two-fold: instilling an abiding rigour in the practice and evaluation of practical science and, secondly, a sense of importance of the philosophical and metaphysical ideas underpinning science. Moreover, through Holmyard,

²¹ Waddington, “Philosophy and Biology” (ref. 20).

²² C. H. Waddington, *The Scientific Attitude* (London: Pelican, 1941), p. xi.

²³ *Ibid.*, p. 53.

Waddington glimpsed practical and theoretical research in action, in scientific debate and the preparation and publication of research papers. This was a more than adequate preparation for university life.

Waddington and Clifton College

Waddington, in common with the most able students at Clifton College, concentrated on a classical education of Latin, Greek, and mathematics until he entered sixth form. His fluency in Greek is apparent in his school essay and also in his love of inventing neologisms, a few of which have become established terms in developmental biology, such as “epigenotype,” “pattern formation,” and “canalisation.” Waddington seems to have re-appropriated the word “epigenetic” and used it in publications from 1942 onwards, although the concept of epigenesis can be traced back to Aristotle. Epigenesis proposes that the form of an organism emerges only gradually over time and is not pre-formed inside the organism.

Waddington was fully immersed into the cultural life of Clifton. The Scientific Society has a long and proud tradition and, in July 1920, it held a summer *conversazione*, in which students demonstrated scientific techniques. Waddington, then fifteen years of age, demonstrated “glass etching.”²⁴ The society was especially active organising geology field trips, in which Waddington participated, deepening his interest in ammonites, which would form a major part of his early years at Cambridge. Waddington was part of the organising committee of the society, as the minute book shows (Fig. 2).

²⁴ Ingram, ““All That You Can’t Leave Behind”” (ref. 4), p. 183.

1923.

President J. A. O. Muirhead Esq.,

Secretary & Treasurer R. J. Bown.

Committee

R. J. Bown (W. H.)

C. S. Stern (P. H.)

S. R. M. Porter (O. H.)

G. H. Waddington (W. H.)

J. W. Tribe (N. T.)

G. A. Virst (S. H.)

J. V. Lucas (S. T.)

D. V. L. Craft. (D. H.)

T. C. Waterfield (B. H.).

Figure 2: Waddington as a member of the organising committee for the Scientific Society of Clifton College, January 1923.

Clifton gave Waddington more than a first-class classical and scientific education. It provided security for a lonely boy with expatriate parents living in the colonies, in an environment enriched with art and sport. English public schools in the 1920s were austere places: emotions were repressed in favour of stiff upper-lips. Facile romantic attachments were eschewed in favour of camaraderie. Congenial company would be almost exclusively male, females were of a different kind.

Fitting into the house was as important as any academic success, especially when it came to team games such as rugby football. Waddington's aptitude for running was noted by Alan Robertson in his biographical memoir.²⁵ In the spring of 1923, Waddington came in fourth in the school's annual Long Penpole Cup cross-country run, a race involving all of the senior boys in the school, a strong achievement, especially as it contributed valuable points for the biggest of prizes, the "cock house championship." Clifton would, inevitably, leave its mark on the young Waddington, as it did on so many others of his generation.

Waddington's broad polymathic interests are widely acknowledged by his biographers. His first and second wives were both artists, and he moved easily between scientific and artistic discourses. In many respects, Waddington represented the antithesis of the attitude derided by C.P. Snow in his Cambridge lecture, *The Two Cultures and the Scientific Revolution*.²⁶ Waddington was younger than Snow, who, in due course, helped Waddington get elected to a fellowship at Christ's College, Cambridge.

Waddington's artistic temperament and critical faculties were evidently nurtured at Clifton and was humorously captured by an unnamed poet in the Clifton College magazine of June 1922:

CUBISM EXTENDED.
(With apologies to C. H. W.).
"I will
Decorate my study
Cubistically,"
He said;
And he took
Ink and white paint,
This
Laughingly
He threw, splash upon splash,

²⁵ Robertson, "Conrad Hal Waddington," (ref. 18), p. 579.

²⁶ C. P. Snow, *The Two Cultures and the Scientific Revolution: The Rede Lecture, 1959* (Cambridge: University Press, 1959).

Over the walls.
 When
 It was dry,
 He brought stencils
 And adorned his walls,
 Until
 Beautiful and ruddy
 Artistically
 The floor
 Had a look
 Of self-restraint.
 Bliss
 Chaffingly
 He called the blotch'd rash
 Over the walls.
 Then—
 But can I
 With my pencil s—
 —uggest the tall s—
 —cheme for the ceiling?
 It gave one the feeling
 Of coffee congealing,
 Of pig-iron annealing,
 Of village bells pealing,
 Of drunken men reeling,
 Of Bolsheviks mealing,
 And heathenish brawls.
 He called it
 The Fun of the Fayre.²⁷

Waddington's writing, such as *Tools for Thought* and *Behind Appearance*

expects his readers to be able to move easily between biology, poetry, art and philosophy, as if there are no distinctions between them.²⁸ This is an approach he seems

²⁷ Anonymous, "Cubism Extended," *Old Cliftonian Magazine* (June 1922), p. 150.

²⁸ C. H. Waddington, *Tools for Thought* (London: Jonathan Cape, 1977); Waddington, *Behind Appearance: A Study of the Relations between Painting and the Natural Sciences* (Edinburgh: Edinburgh University Press, 1969).

to have developed at Clifton. Writing about the (then) newly published T. S. Eliot poem, *East Coker* (1940), Waddington quotes Picasso:

One must act in painting, as in life, directly.... We must not discriminate between things. Where things are concerned, there are no class distinctions. Again, listen to Eliot pointing out that the only way forward, even the only way to remain fully alive, is to deny the facile romantic ecstasy and to forget the traditional knowledge:

*In order to arrive there, to arrive where you are, to get from where you are not, you must go by way wherein there is no ecstasy. In order to arrive at what you do not know you must go by way which is the way of ignorance.*²⁹

In order to arrive there, Waddington has stripped the poetry of its religious and mystical symbolism, abstracted its meaning into a rational core. This is a very modernist approach to using literary sources and owes much to Holmyard and the liberal-thinking culture of Clifton, which counts as alumni the artist Roger Fry and Thoby Woolf (Virginia Woolf's brother), both instrumental in the Bloomsbury Group of modernist thinkers and also the literary critic, Arthur Quiller-Couch.

Waddington and the School Essay (1923)

Whilst Waddington's school essay invites contemporary critical scrutiny, it is important to recognise that it was also just a routine piece of schoolwork. Clifton in this period was a rather austere place. A good piece of written work would be recognised by the

²⁹ Waddington, *The Scientific Attitude* (ref. 22), p. 62, emphasis in the original; T. S. Eliot, *East Coker* (London: Faber and Faber, 1940).

absence of criticism, rather than by praise.³⁰ The college has report card, recording Waddington's progress through the school (Fig. 3). It records steady progress through the middle years and promise in the sixth form. The sixth form entry, probably in Holmyard's hand, acknowledges the achievement of his study in chemistry, Spanish and Arabic, subjects that facilitated his essay on alchemy.

PRIVATE.

CLIFTON COLLEGE.

Name..... Waddington, C. H......

Born..... 8th November..... 1905..... Entered..... September 26th..... 1919.....

Previous School. M. H. Asterley Esq., Aymerstrey House, Malvern.

Form.	Date.	REPORTS.
<u>14/3</u>	<u>1919. 3</u>	<u>Good start.</u>
	<u>20. 1</u>	<u>Quite sat. Langs weak.</u>
<u>α</u>	<u>2</u>	<u>Sc on steadily & fr.</u>
<u>γ</u>	<u>3</u>	<u>intell - not thorough.</u>
<u>α(c)</u>	<u>21. 1</u>	<u>Engl good - classics weak.</u>
	<u>2</u>	<u>"</u>
	<u>3</u>	<u>Sels good - "</u>
	<u>22. 1</u>	<u>Sc on well. Sc & maths good.</u>
	<u>2</u>	<u>"</u>
<u>V1</u>	<u>3</u>	<u>" promising chem.</u>
	<u>23. 1</u>	<u>" also Spanish & Arabic.</u>
	<u>2</u>	<u>Good - will read in Chem. H.C. Sp IV</u>

Figure 3: Waddington's internal school report at Clifton College.

Waddington's sixth form essay "Alchemy" is archived at the University of Edinburgh.³¹ It runs to 97 double-spaced typewritten pages. As sign of Waddington's

³⁰ Ingram, "All That You Can't Leave Behind" (ref. 4), p. 183.

³¹ C. H. Waddington, "Alchemy: An Essay written in the Sixth Form—Clifton College, 1923," papers of Conrad Hal Waddington, Coll-41/2/1/1, Edinburgh University Library

emerging interest in the visual arts, the essay is liberally illustrated with pencil sketches from published works. Fig. 4 shows Waddington's sketch based on the Chrysopeus of Cleopatra, a papyrus written by a third-century Greek Egyptian alchemist. The concentric circles (top left) enclose the signs for gold, silver and mercury. On the outer circle is written in Greek: "One is the all, and by it the all and towards it the all: and if the all is not contained by the all, the all is nothing."³² The lower two images were reproduced in the Serbelloni presentation.³³

Special Collections, accessed 17 April 2019 from http://lac-archives-live.is.ed.ac.uk:8081/repositories/2/archival_objects/15407.

³² *Ibid.*, p. 30.

³³ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 3; C. H. Waddington, *Towards a Theoretical Biology* (ref. 6), p. 74.

Figure 4: the Chrysopeus of Cleopatra. From Waddington's school essay, 1923.

Interestingly, they represent the metaphysical ouroboros and the practical alembic (distillation vessel), reinforcing the points made above about the balanced approach being engendered.

The essay is such a fine piece of writing that it is easy to forget it was written by a schoolboy. The present author has been Head of Science at Clifton and privileged to read many good pre-university essays, but this ranks among the finest. It is comparable with the school essays of the Nobel Prize winner, John Kendrew, FRS, archived at the Bodleian Library, Oxford. (Kendrew was also a protégé of Holmyard.) Nonetheless, despite the mature style, signs of youth are occasionally glimpsed. “Fundamental” [*sic*] appears on more than one occasion. On page 69 the (presumably, tiring) Waddington writes “He [Ibn Sina] was followed by two unimportant men, Ghazzali, a philosopher, and Tughta’i al Hasan ibn Ali.” This comment earned the rejoinder from Holmyard, “[Ghazzali] was unimportant only in so far as alchemy is concerned. He was a very great man in other branches of learning.”³⁴

Generally, though, the tone of the essay is respectful, although not without critical reflection: “For nearly a hundred years after this Arabic alchemy underwent a decline. Little work of any sort was done and that little was spoiled by being overlaid with mysticism and allegory, a fault from which Jabir and Ar-Razi had kept remarkably free.”³⁵ This trait, characteristic of the mature man, is surely the influence of Holmyard, who writes

It may be a more scholarly attitude to take nothing as true that cannot be proved, but when one is dealing with such an obscure subject as alchemy, in an alien civilisation of centuries ago, such a method of attack is not very fruitful. With due reservation and caution, more progress can be made by paying respect to accepted beliefs until they can be shown to be untenable.³⁶

The choice of subject matter of the essay is logical and classical, working systematically

³⁴ Waddington, “Alchemy” (ref. 31), p. 69.

³⁵ *Ibid.*

³⁶ Holmyard, *Alchemy* (ref. 12), p. 64.

through Egyptian, Greek and Arabic thought. In researching this, Waddington had access to a collection of popular and specialist books and manuscripts contained within a single bookcase called by the school the “Holmyard Collection.” Waddington acknowledged John Edward Mercer’s *Alchemy: Its Science and Romance* and uses a quotation from Geber (Jabir).³⁷ There were relatively few “popular” accounts of alchemy in the Holmyard Collection, mostly, though, the collection contains academic papers and books in English, German and Arabic.

Waddington neglected some sources that were available to him, including the rare English alchemical work “the ordinal of alchemy” collected by Elias Ashmole (1618), containing the writing of Thomas Norton, a Bristolian alchemist. This work evidently fascinated Holmyard, a proud Somerset man, who devoted twelve pages of his Pelican paperback to the work and edited a facsimile edition.³⁸

What fascinated Waddington were the philosopher’s egg and the ouroboros, neither of which feature in Holmyard’s two popular works on alchemy.³⁹ The ouroboros is a serpent that is eating its tail (Fig. 5).

³⁷ J. E. Mercer, *Alchemy: Its Science and Romance* (London: Society for Promoting Christian Knowledge, 1921), p. 95.

³⁸ Thomas Norton, *The Ordinall of Alchimy* (London: Edward Arnold & Co., 1928).

³⁹ E. J. Holmyard, *Chemistry to the Time of Dalton* (Oxford: Oxford University Press, 1925); Holmyard, *Alchemy* (ref. 12).

Figure 5: the ouroboros. From Waddington's school essay, 1923.

This ouroboros is found in the manuscript *Parisinus graecus*. It has three concentric rings, with three ears and four feet. Waddington tells us that the “three ears represent the three vapours, the four feet represent the four fundamental substances, lead, copper, tin and iron.”⁴⁰ Joseph Needham and Tsuen-hsuei Tsien suggested that these three sublimed vapours (*aithalai*) probably represent sulphur, mercury and arsenic.⁴¹ Waddington continues: “Ouroboros is regarded as the symbol of the alchemist's work, which has no beginning, and

⁴⁰ *Codex Parisinus Graecus* 2327 in the Bibliothèque Nationale, Paris; Anonymous, “alchemy,” *The Oxford Classical Dictionary* (Oxford: Oxford University Press, 2012), 10.1093/acrefore/9780199381135.013.260 Waddington, “Alchemy” (ref. 31), pp. 23–25.

⁴¹ Joseph Needham and Tsuen-hsuei Tsien, *Science and Civilisation in China. Vol. 5, Chemistry and Chemical Technology* (Cambridge: Cambridge University Press, 1985).

no end, but is merely hastening of the cycles of nature.”⁴² The world’s egg was “used to designate the fecundity of the earth and in particular the alchemists’ work of engendering gold.” In Egyptian thought, Osiris placed in the egg of Creation “two white pyramids, symbolical of the good of the Earth” and Typhon introduced twelve black pyramids, symbolical of the “evils with which he dowered mankind.”⁴³ Heady stuff for a young man who was inspired to spend much of his life as a developmental biologist, actively studying the “fecundity” of living eggs.

It is in the section on Arabic alchemy that the tone changes and becomes more authoritative, as Holmyard’s voice breaks in. There is a considerable emphasis on Jabir ibn Hayyan and immediately after this, a detailed rehearsal of the case for presuming ibn Hayyan and Geber to be one. The flow of ideas between Holmyard and Waddington is clear in these passages. Waddington writes:

He [Jabir] was a practical chemist and made many independent researches and discoveries and insisted, for the first time, on the necessity of checking theories by experiment. He banished magic from the art and started the movement which was to raise alchemy to the dignity of a science.⁴⁴

This is a significant passage. It shows that, even at school, Waddington is aware of the inherent tension between the reductionist “scientific method” necessary to collect empirical evidence and the “highly poetic metaphysics” surrounding the ontogeny of

⁴² Waddington, “Alchemy” (ref. 31), p. 23.

⁴³ Waddington, “Alchemy” (ref. 31), p. 24.

⁴⁴ Waddington, “Alchemy” (ref. 31), pp. 61–97, quote on p. 63.

nature.⁴⁵ But he is also mindful of the connections between them. Holmyard writes of Jabir's conception of "balance," a metaphysical conception that described the relations between all metals: "His balance was an equilibrium of 'natures', and a great deal of work was devoted to establish the equilibrium figures in gold – the perfect metal – so that the same balance could be effected in base metals. Thus bringing about their transformation."⁴⁶ The schoolboy Waddington recognises the dignified status of science and that it is different from the metaphysics. He praises Jabir for "banishing magic from the art." In this essay, the description and cataloguing of the metaphysical ontogeny of ideas is as important as the emergent empirical chemistry. They are two destinations on the same road, but they are not the same place. The essay achieves a balance between metaphysics and empiricism that characterises Waddington's future work as a scientist.

Years later, Waddington would "banish the magic" from the world's egg and the ouroboros, leading him into the epigenetic landscape. Before he could have the confidence to do this, he would need to acquire "a large body of more explicitly rationalised thinking," namely the process philosophy of Alfred North Whitehead, and think more clearly about the processes of abstraction.⁴⁷

Waddington and Whitehead (1929–1931)

Waddington's days at the University of Cambridge from 1923 onwards have been

⁴⁵ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 3; Waddington, *Towards a Theoretical Biology* (ref. 33), pp. 73–74.

⁴⁶ Holmyard, *Alchemy* (ref. 12), pp. 73–74.

⁴⁷ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 3; Waddington, *Towards a Theoretical Biology* (ref. 6), p. 74, C. H. Waddington, *The Process of Abstraction and the Vitalism-Mechanism Controversy* (Edinburgh: University of Edinburgh Press, 1931).

meticulously researched by Erik Peterson.⁴⁸ Three features emerge: Waddington's gradual disillusion with his formal studies in geology, his growing interest in process philosophy linked to organicism, and his enjoyment of stimulating conversation and debate.

Waddington's prizewinning Arnold Gernstenberg essay concerned the emerging metaphysical process philosophy of Whitehead.⁴⁹ Whitehead's *An Enquiry Concerning the Principles of Natural Knowledge*, *The Concept of Nature*, and *Science and the Modern World* were all available for Waddington and his colleagues to study in the Theoretical Biology Club, which included Gregory Bateson, Joseph Henry Woodger, Dorothy Moyle and Joseph Needham.⁵⁰

Whitehead's work was rational, emphasising that the fundamental units of nature are not atoms, forces or energy, but "occasions of experience," that he called "events." Atoms, forces and energy are objects within the events that interact together in time and in space. Events are subject to processes of development, "being" and "becoming" something new. "An event in passing becomes part of larger events; and thus the passage of events is

⁴⁸ Erik L. Peterson, *The Life Organic: The Theoretical Biology Club and the Roots of Epigenetics* (Pittsburgh: University of Pittsburgh Press, 2016).

⁴⁹ Waddington, "Philosophy and Biology" (ref. 20).

⁵⁰ Alfred North Whitehead, *An Enquiry Concerning the Principles of Natural Knowledge* (Cambridge: Cambridge University Press, 1919); Whitehead, *The Concept of Nature: The Tarner Lectures Delivered in Trinity College, November 1919* (Cambridge: Kessinger Publishing, 1920); Whitehead, *Science and the Modern World: Lowell Lectures* (London: Macmillan, 1925); Peterson, *The Life Organic* (ref. 48) pp. 104–17.

extension in the making. The terms 'the past,' 'the present,' and 'the future' refer to events. The irrevocableness of the past is the unchangeability of events."⁵¹

Whitehead's thinking was firmly rooted in the Pre-Socratic philosophy of Heraclitus' πάντα ῥεῖ (*panta rhei*), "everything flows," emphasising the essentially connectedness of objects in space and time: "ὁδὸς ἄνω κάτω μία καὶ ὡυτή [Hodos anō katō mia kai ōute] / The path up and the path down is one and the same."⁵² Waddington took from Whitehead the presumption, "The raw materials from which we start to do science - or with which we finish testing a theory are 'occasions of experience'."⁵³ Objects are "events" in time, which interact with other events, creating new events. Waddington calls these interactions "ingression."

A physical object can also be looked on as a collection of scientific objects. A scientific object embodies the potency of the event in which it has ingression for modifying other events. From the behaviour of any physical object we construct a set of objects such that the behaviour would be explained by the supposition that the physical object consists of a collection of some of this set of objects: the objects in this set are scientific objects, such as atoms, electrons, etc.⁵⁴

The formation of new events is called "concrecence." The ways that new events concrecence is shaped by patterns (or prehensions) formed by preceding events, which provide information in the form of datums. The existence of new events clings firmly to the past and projects into the immediate future, since these events will, in due course, influence the formation of future events. This is a world where events regulate other events and are themselves controlled by events.

⁵¹ Whitehead, *An Enquiry Concerning the Principles of Natural Knowledge* (ref. 50).

⁵² Heraclitus (ref. 1), p. 51.

⁵³ Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 4.

⁵⁴ Waddington, "Philosophy and Biology" (ref. 20), p. 41.

The Concept of Nature begins with a clear rejection of the “facile bifurcation that separated subjects from objects.”⁵⁵ When we, as observers, perceive the red flames and warmth of a fire, we may experience the emotional memories of happy evenings spent in good company in front of a fire and a strong sense of safety. On the face of it, this seems quite different to the atoms, forces and energy stores that generate the flames. However, Whitehead sees this as a “facile” (superficial) distinction that cannot be valid. According to Whitehead, a bird singing in a tree produces a song that is perceived by other birds, which may invoke different responses from a rival male or a potential female suitor. The same song is perceived differently, invoking different biological responses.

In addition to rejecting the Cartesian duality of “body” and “mind,” Waddington rejected other consequential bifurcations such as mechanism and vitalism leading him to a form of organicism, emphasising the importance of the integrated organism.⁵⁶

Moreover, there is a reciprocal interaction between the parts and the whole. For the parts would not be what they are if they did not belong to the whole, while the whole is made up of a certain relation between the parts. In this sense, the whole can be called an organism without putting too artificial a meaning on that word.⁵⁷ Other consequential bifurcations, such as those between an organism and its environment as well as between genes and their environment were also rejected in favour of their roles as events containing interacting objects that stimulate the concrescence of new events.

The rejection of the separation between the events being perceived and the perceiver is a matter of significance for the scientist, and Waddington wrote about this at length in an

⁵⁵ Whitehead, *The Concept of Nature* (ref. 20), pp. 26–34.

⁵⁶ Peterson, *The Life Organic* (ref. 48), p. 151.

⁵⁷ Waddington, “Philosophy and Biology” (ref. 20), p. 58.

unpublished paper in 1931.⁵⁸ In it, he argues, that science is not interested in the relations between the observer and the objects perceived. Rather, it is interested in the content of the perception, which it regards as both real and external to the observer.

This is far from a rejection of Whitehead's paradigm; rather, it is an intentional act of the scientist to abstract from the complexity of interacting objects within events, those "scientific objects" which best represent the interactions chosen for study. This he terms "abstraction." Abstraction is essential if causality between interacting objects is to be established.

Abstraction...enables one to eliminate what is inessential for some point of view, and to concentrate on what is essential for that point of view... by gradually eliminating the features which are peculiar to any particular instance, obtain concepts which are of progressively wider application and greater generality... thus yield[ing] a serial set of abstractions.⁵⁹

Waddington grades levels of abstraction, rating scientific objects (such as atomic particles) lower than cells and organisms. Complex entities related to the perceiver, such as "morals, aesthetics" have the highest level of organisation.⁶⁰ Presumably, values, attitudes, emotions, memories and religious experiences would have similarly high levels of organisation. Science, he advises, should not attempt to deal with such entities.

Abstraction is a means to the end of allowing empirical science to proceed. However, the accumulation of empirical evidence is not an end in itself.

⁵⁸ Waddington, *The Process of Abstraction* (ref. 47), p. 1–21.

⁵⁹ Waddington, *The Process of Abstraction* (ref. 47), p. 7.

⁶⁰ Waddington, *The Process of Abstraction* (ref. 47), p. 18.

Thus, arises one of the paradoxes of the scientific method: it is necessary both to keep continually in mind the actual events which have been observed, the actual experimental evidence, and at the same time to be as bold as possible in leaving the particular instances and proceeding to wide-reaching generalities.⁶¹

Waddington uses the term “pathway” to describe a process of abstracting objects from the complexity of events. New scientific evidence has to be generalised and connected back to the event itself. Travel on this pathway is both up and down.

Abstraction necessarily involves a loss of information, a reduction in complexity. When a single set of events have objects that are involved in a number of different types of interactions, which can be contrasted with each other, then these are described as “paths lying on different routes.”⁶² For the complex event that is a stem cell, interactions between the cell contents and the environment can vary considerably, resulting in different cell types being produced. Each type of interaction results in a different type of cell, along developmental “paths lying on different routes.”

Here, embedded in Whiteheadian process philosophy, hidden in an unpublished paper, is an event that will eventually develop into the epigenetic landscape. It is firmly rooted in the Clifton alchemy paper of 1923, where Jabir banished “magic from the art” by abstracting empirical chemistry from romantic metaphysics, but it is boldly looking towards the future.

⁶¹ Waddington, *The Process of Abstraction* (ref. 47), p. 6.

⁶² Waddington, *The Process of Abstraction* (ref. 47), p. 8.

The Birth of Endeavour (1941–1942)

On 2 December 1940, during the blitz of World War II, a bomb fell on a Clifton College sports field, metres away from where pupils were sheltering. The bomb caused considerable damage but, fortunately, no injuries.⁶³ The headmaster, Bertrand L. Hallward decided that the college should immediately begin an evacuation to Bude, Cornwall. The evacuation meant that the emphasis on practical science would have to be reduced because the science laboratories in Bude were shared with two other schools (one several miles distant) and could only be used after 4:00 pm.⁶⁴

At the start of the Lent term 1941, Holmyard unexpectedly retired from Clifton College after 21 years of service. He was at pains to explain that the evacuation was *not* the reason for his resignation. Publicly, he was vexed about a reduction in his salary, prompted by a recent decision by the college council to eliminate the heads of department allowances.⁶⁵ Privately, he had acute family concerns. In a letter to the Headmaster, Holmyard wrote:

It is, I hope, unnecessary for me to say that my heart is still very much with Clifton science. It would be a fine job to show boys how much science can be done with how little apparatus—as witness Dalton, Berzelius, Perkin, von Baeyer and, above all Scheele.⁶⁶

⁶³ Cheryl Trafford, *The Best School of All': 150 Years of Clifton College* (London: Third Millennium Publishing Limited, 2009), p. 38.

⁶⁴ Ingram, "Science at Clifton" (ref. 4), p. 14.

⁶⁵ E. J. Holmyard, Letter to Headmaster of Clifton College, 21 January 1941, Clifton College Archives, RS2/273.

⁶⁶ E. J. Holmyard, Letter to Headmaster of Clifton College, 31 March 1941, Clifton College Archives, RS2/273.

The headmaster wrote to Holmyard again in March 1941 from Bude, trying to get Holmyard to reverse his decision. Hallward offered him a partial restoration of the allowance and the Head of Science position. Holmyard again refused, partly because in the intervening weeks he had, sadly, become a widower, on the death of his wife Ethel on 19 February 1941. He wrote:

One compelling reason for my decision is that, here, I am within walking distance of my boy at Butcombe, whereas from Bude he would be quite inaccessible. I think it my duty, too, to see that the death of his mother does not entirely deprive him of home life, and so I must keep this little place going for his sake.⁶⁷

There is another, more covert, reason for the rejection of the peace offer. By then, Holmyard was engaged on a different project that would have significance beyond the college walls. In the early weeks of January 1941, just as he resigned from Clifton, Holmyard wrote to Dr. Roland Slade, chief research chemist for Imperial Chemical Industry (ICI), informing him of his retirement and that he was “available for work.”⁶⁸ Serendipitously, ICI was formulating plans to launch a wartime science journal, and Holmyard was appointed editor in March 1941.

The journal was intended to showcase to the world the best of British science, at a time when Britain was “besieged” by the events of the war. The name *Endeavour* was chosen to signify the adventuring spirit of Captain Cook and Joseph Banks’s scientific journey to the South Pacific seas in 1768.

Holmyard worked from his house in Wraxall, Somerset, travelling occasionally to meetings in London. He successfully argued for an editorial panel, with “Dr. C. H. Waddington (genetics), Cambridge University” part of it. The pair worked together again for the first time in eighteen years. The first issue of the journal was published in January 1942,

⁶⁷ *Ibid.* Butcombe Court, Somerset, is where Clifton College Preparatory School pupils were evacuated during World War II.

⁶⁸ Sidney Rogerson, “The Birth of Endeavour,” *Endeavour* 22, no. 4 (1977): 137–39.

and it carried a statement from Lord McGowan, chairman of ICI, who promised, “*Endeavour* will act as a vessel to carry overseas news of the continuing vitality and progress of the sciences, which no frontiers but are directed to improving the common lot of all men.”⁶⁹

Waddington’s contribution to that edition, “the epigenotype,” certainly fits that aspiration. It is a reworking of a lengthy paper, an account of the wing development of the wing in *Drosophila*.⁷⁰ This involved a detailed study of normal wing development and separate investigations of 38 gene mutations that “affect 16 different, but not independent, processes which occur during wing development.”

This work was mostly undertaken in the academic year 1938–1939 in Caltech, Pasadena, California, in Thomas Hunt Morgan’s fly laboratory. Morgan also had a background in embryology before turning to genetics, and he shared similar views about genes being “heuristic devices,” representing the networks and processes that lead to the development of the phenotype.⁷¹ In 1934, Morgan wrote:

Concerning the matter of functioning of genes during development, I have contrasted...two possible views, and suggested a third.... It is known that the protoplasm of different parts of the egg is somewhat different, and that the differences become more conspicuous as the cleavage proceeds.... From the protoplasm are derived the materials for the growth of the chromatin and for the substances manufactured by the genes. The initial differences in the protoplasmic regions [of a fertilised egg] may be supposed to affect the activity of the genes. The genes will then in turn affect the protoplasm, which will start a new series of reciprocal reactions. In

⁶⁹ H. D. McGowan, “Our Purpose,” *Endeavour* 1, no. 1 (1942): 1.

⁷⁰ C. H. Waddington, “The Genetic Control of Wing Development in *Drosophila*,” *Journal of Genetics* 41, no. 1 (1940): 75–139.

⁷¹ Peterson, *The Life Organic* (ref. 48).

this way we can picture to ourselves the gradual elaboration of differentiation of various regions of the embryo.⁷²

Waddington's *Endeavour* paper is generally remembered for being the first use of the term "epigenotype" and for its re-acquisition of the term "epigenesis." Waddington defined the latter more broadly than others had in contemporary genetics:

The...more important part of the task is to discover the causal mechanisms at work, and to relate them as far as possible to what experimental embryology has already revealed of the mechanics of development. We might use the name "epigenetics" for such studies, thus emphasizing their relation to the concepts, so strangely favourable to the classical theory of epigenesis, which have been reached by the experimental embryologists.

The epigenotype is defined as a complex of developmental processes that lie between the genotype and the phenotype.

It consists of concatenations of processes linked together in a network, so that a disturbance at an early stage may gradually cause more and more far reaching abnormalities in many different tissues and organs.⁷³

Genes are not peripheral to these processes, they have central roles in regulating and guiding developmental events. Their activity is, in turn, regulated by changes in the developmental environment. Waddington concludes this three-page paper with the bold statement that "the analysis of the effects of genes has now progressed far enough to become merged with experimental embryology."⁷⁴

The *Endeavour* paper was a "hidden gem," whose significance has been overlooked.

In the paper celebrating the 70th anniversary of *Endeavour*, there is a full account of the

⁷² T. H. Morgan, *Embryology and Genetics* (New York: Colombia University Press, 1934), pp. 9–20.

⁷³ Waddington, "The Epigenotype" (ref. 5), p. 2.

⁷⁴ *Ibid.*, p. 20.

production of the first issue, but with no reference to Waddington's paper, even though, it was attracting considerable attention in the evolutionary developmental biology community after it was republished in in the *International Journal of Epidemiology* in 2012.⁷⁵

Scott Gilbert, in an accompanying commentary, described the paper as a “truly revolutionary view of biology.” Quoting Jonathan Bard, he says:

Before Waddington, genes had very little to say about development; Waddington was the first to say explicitly that the development of a phenotype (epigenesis) is the sum of genetic expression and tissue interactions. What Waddington had presented was nothing less than the first detailed genetic pathway of organ development.⁷⁶

Brian Hall lists three points that are “foundational to modern evolutionary developmental biology,” each of which was first established in Waddington's 1942 *Endeavour* paper: (1) “phenotypes must be studied in order to reach conclusions about the genotypes,” (2) “between the genotype and phenotype, and connecting them to each other, there lies a whole complex of developmental processes,” and (3) “the analysis of the effects of genes has now progressed far enough to become merged with experimental embryology... and in practice come together in an attack on the still unresolved problems of the epigenotype.”⁷⁷

Although the concept of the “epigenotype” is the “now-accepted truth” in developmental biology, the contemporary use of the term “epigenetics” is restricted to the technical one of a genotype containing specific modifications, such as DNA methylation or histone modifications.⁷⁸ This is a much narrower, and more reductionist, use of the term that Waddington originally envisaged.

⁷⁵ Christopher M. Tancock, “A Worthy Endeavour,” *Endeavour* 2, no. 38 (2014): 59–62; Waddington, “The Epigenotype” (ref. 5).

⁷⁶ Gilbert, “Commentary” (ref. 5), p. 22.

⁷⁷ Hall, “EvoDevo Concepts in the Work of Waddington” (ref. 3), p. 201.

⁷⁸ Jonathan B.L. Bard, “Waddington's Legacy to Developmental and Theoretical Biology,” *Biological Theory* 3, no. 3 (2008): 188–97. For contemporary uses of the term, see T. Tada,

The Emergence of the Epigenetic Landscape (1939–1940)

Jan Baedke, Antonine Nicoglou, Mallory Nicole Squier, and Erik Peterson have written extensively about the development of the metaphor of the epigenetic landscape and its subsequent impact on biology and wider fields. It was developed in discussion and collaboration with many colleagues in the Theoretical Biology Club, such as Joseph Henry Woodger and the Needhams, who shared an interest in Whitehead's process philosophy.⁷⁹ At the heart of the metaphor is a ball of differentiating tissue moving across a physiochemical surface. As early as 1932, Waddington compared the differentiation of a chick blastoderm to "a ball impelled by a set of different forces along a plane surface," and in 1936, Joseph Needham's *Order and Life* describes a number of different models that they were trying, such as a series of concentric cones, and a plaster model of embryonic development, both of which prefigure the epigenetic landscape.⁸⁰

et al., "Epigenotype Switching of Imprintable Loci in Embryonic Germ Cells," *Development Genes and Evolution* 207, no. 8 (1998): 551–61; A. Mussa, *et al.*, "(Epi) Genotype–Phenotype Correlations in Beckwith–Wiedemann Syndrome," *European Journal of Human Genetics* 24, no. 2 (2016): 183; and Wei-Li Lin *et al.*, "The Genotype and Epigenotype Synergize to Diversify the Spatial Pattern of Expression of the Imprinted H19 Gene," *Mechanisms of Development* 82, no. 1–2 (1999): 195–97.

⁷⁹ Jan Baedke, "The Epigenetic Landscape in the Course of Time: Conrad Hal Waddington's Methodological Impact on the Life Sciences," *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 44, no. 4 (2013): 756–73; A. Nicoglou, "Waddington's Epigenetics or the Pictorial Meetings of Development and Genetics," *History and Philosophy of the Life Sciences* 40, no. 4 (2018), <https://doi.org/10.1007/s40656-018-0228-8>; Peterson, *The Life Organic* (ref. 48); Susan Merrill Squier, *Epigenetic Landscapes: Drawings as Metaphor* (Durham: Duke University Press, 2017).

⁸⁰ C. H. Waddington, "Experiments on the Development of Chick and Duck Embryos, Cultivated in Vitro," *Philosophical Transactions of the Royal Society of London Series B-Containing Papers of a Biological Character* 221 (1932): 179–230; Joseph Needham, *China*

The first formal appearance of the epigenetic landscape occurred in *Organisers and Genes* (1940) (see Fig. 6a).

Figure 6 Two views of the epigenetic landscape, from Waddington's *Organisers and Genes*, 1940.

Squier has discussed circumstances in which the Waddington commissioned the celebrated abstract artist John Piper to produce the painting that Waddington described as an “interpretation of my somewhat romantic conceit, the epigenetic landscape.”⁸¹ This painting, Squier claims, is important in the canon of Piper's work, as it represents a stage in the

and the Origins of Immunology (Hong Kong: University of Hong Kong, Centre of Asian Studies, 1980).

⁸¹ Squier, *Epigenetic Landscapes* (ref. 79); C. H. Waddington, *Organisers and Genes* (Cambridge: Cambridge University Press, 1940), p. viii; for visualisations, see the frontispiece and p. 83.

transition from “abstraction to the figurative.”⁸² However, as she points out, the picture is not quite all it seems as the “water flows both up to the mountains and down to the sea.”⁸³

Waddington accepted that “it would be difficult to find a similar configuration in any piece of country...but it is an amusing landscape to picture to oneself.”⁸⁴ The system of valleys branch downwards, “like a delta.” He described the valleys:

As one goes downhill, the valley which was originally wide and gently sloping, branches into more and more subdivisions, some of which (representing tracks realised only under the influence of special genes or environmental conditions) may be hanging valleys whose floors disembouch up the side, above the main valley bottom.⁸⁵

The hanging valley floor is the first of the channels, nearest to the observer. In reality, if it were a delta valley, it could be closest to the sea and pointing away from the observer. As Squier suggests, this painting is much less figurative than first meets the eye.

Waddington included a 1932 Picasso painting of Marie-Thérèse Walter in *The Scientific Attitude* (1941). He called the painting “blonde,” although its contemporary catalogue listing is “Nude Woman in a Red Armchair” (Fig. 7).

⁸² Squier, *Epigenetic Landscapes* (ref. 79), p. 25.

⁸³ *Ibid.*, p. 21.

⁸⁴ Waddington, *Organisers and Genes* (ref. 80), p. 93.

⁸⁵ *Ibid.*, pp. 45, 95.

Figure 7: “Blonde/ Nude Woman in a Red Armchair, by Picasso, 1932.

Waddington said of the painting, “He [Picasso] has put in the profile and full-face both at once, presumably because he liked them both, and realised that they belonged together.”⁸⁶ The same argument can be made for the positioning of the channels in the Piper painting.

Squier observes in the representation of the epigenetic landscape, a tension “between the aesthetic and the programmatic, between context and content, or between holism and reductionism.”⁸⁷ A partial resolution would to see the Piper painting as a representation of the ontological relations between the genotype and the environment in and around the developing

⁸⁶ Waddington, *The Scientific Attitude* (ref. 22), between pp. 91–92; for the catalogue listing: “N06205 Femme nue dans un Fauteuil rouge (Nude Woman in a Red Armchair), 1932,” accessed 17 April 2019 from <https://www.tate.org.uk/art/artworks/picasso-nude-woman-in-a-red-armchair-n06205>

⁸⁷ Squier, *Epigenetic Landscapes* (ref. 79), p. 22.

tissue (Fig. 6a). Fig. 6b is an epistemological representation of these general relations in terms of the development of the antennae in *Drosophila*. The two images are intended to be read together, each being diminished by the absence of the other. The former is holistic metaphysical thinking and the latter is reductionist and empirical, but they are two destinations, although “the path up and the path down is one and the same.”⁸⁸

The Practical Consequences of Metaphysical Beliefs

Although Waddington wrote extensively about his interest in Whitehead’s process metaphysics, all of the articles were written in the twilight of his career. Waddington’s early writings (1929 and 1931) exist only as unpublished manuscripts in the Waddington archive in the University of Edinburgh.⁸⁹ He self-effacingly explains his reticence to publish his view: “Since I am an unaggressive character, and was living in an aggressively anti-metaphysical period, I chose not to publicly expound these philosophical views.”⁹⁰ Certainly, *The Scientific Attitude*, written in 1941, is aggressively anti-metaphysical, although this might reflect wartime exigencies and the philosophically fashionable logical positivism:

Science is essentially analytical. It can look at any phenomenon, from something as cold and empty of significance as the orientation of a molecule on the surface, to the bearing of a man whose head is bloody but unbowed. But it must get its items separated; anything subjected to scrutiny be isolated from the mush of general goings-on in which it is normally embedded, it must be defined, or if it cannot be formally defined, at least one must be able to indicate what exactly is

⁸⁸ Heraclitus (ref. 1), p. 51.

⁸⁹ Waddington, *Towards a Theoretical Biology* (ref. 6); Waddington, *The Evolution of an Evolutionist* (ref. 6); Waddington, *Behind Appearance* (ref. 28); Waddington, “What I Was Reading, Fifty Years Ago,” *Nature* 258, no. 5530 (1975): 20–21, Waddington, “Philosophy and Biology” (ref. 20); Waddington, “The Process of Abstraction and the Vitalism-Mechanism Controversy” (ref. 47).

⁹⁰ Waddington, *Towards a Theoretical Biology* (ref. 6), p. 81.

the thing one is talking about, and what else is a fortuitous rag-tag-and-bobtail that happens to be cluttering it up at the moment.⁹¹

Waddington drew attention to the importance of his schooldays at Clifton in a remarkable autobiographical contribution to a debate on the importance of metaphysical beliefs to biology at the second symposium on theoretical biology in the Villa Serbelloni, Lake Como, in August 1967. This was published in the conference proceedings and included in his *The Evolution of an Evolutionist*.⁹² Squier has discussed the importance of the contribution to the conference as a whole, which are also considered by Peterson and Slack.⁹³

Waddington's paper follows contributions from David Bohm, a theoretical physicist and Marjory Grene, a philosopher.⁹⁴ Both, in their different ways, were arguing for the inclusion of metaphysics in science. Bohm says:

It seems clear that everybody has got some kind of metaphysics, even if you think he hasn't got any. Indeed, the practical "hard-headed" individual who "only goes by what he sees" generally has a very dangerous kind metaphysics, i.e. the kind of which he is unaware... Such metaphysics is dangerous because, in it, assumptions and inferences are being mistaken for directly observed facts, with the result that they are effectively riveted in an almost unchangeable way into the

⁹¹ C. H. Waddington, *Science and Ethics* (London: George Allen and Unwin, 1942); Waddington, *The Scientific Attitude* (ref. 22), p. 44.

⁹² Waddington, *The Evolution of an Evolutionist* (ref. 6), p. 2; Waddington, *Towards a Theoretical Biology* (ref. 6), pp. 61–69.

⁹³ Squier, *Epigenetic Landscapes* (ref. 79), pp. 30–44; Peterson, *The Life Organic* (ref. 49), Slack, "Conrad Hal Waddington" (ref. 3).

⁹⁴ Waddington, *Towards a Theoretical Biology* (ref. 6), p. 42.

structure of thought. What is called for is therefore each one of us to be aware of his metaphysical assumptions to the extent that this is possible.⁹⁵

Greene went further, arguing that the conference produced “two paradigms, one orthodox and relatively restricted (and restricting) in scope, the other heterodox and comprehensive.”⁹⁶

Through this she indicates that reductionist material science is the orthodoxy and David Bohm’s metaphysics as the heterodoxy. Further she makes the audacious claim that during the conference: “the first [scientific orthodoxy] was literally comprehended—that is described and explained—by the second [heterodox metaphysics].”⁹⁷ The conference contained a number of prominent practical scientists (including biologist John Maynard Smith, neuroscientist Richard Gregory and theoretical chemist Christopher Longuet-Higgins) who were, perhaps, Bohm’s “hard-headed” materialists. Thus, Waddington’s contribution was presented in something of a febrile atmosphere. Squier’s analysis of the conference perceptively suggests that Waddington was torn between the claims of the two paradigms, which led him to retreating from his metaphysics and ultimately from the epigenetic landscape. She sees orthodox science and metaphysics as separate paradigms, whereas Greene sees the orthodox as being subsumed by the heterodox.

The evidence from both the 1923 alchemy essay and the 1931 essay on abstraction suggest that Waddington saw these paradigms as necessary and complementary. The epigram from Heraclitus, that “the path up and the path down are the same” provides a metaphor for the process of abstraction and reification that Waddington uses as he walks up and down the path from the metaphysics to the empiricism and back again.

Waddington’s response to Greene’s clever, witty, and wise contribution, is parsimonious when compared to his response to Bohm’s contribution, which he welcomes because of its obvious congruence with the ideas of Whitehead. Squier writes at length about this response, suggesting that it was “implicitly gendered” and not in the spirit of the interdisciplinary inquiry that was the primary aim of the conference.

An alternative reason for Waddington’s (and the other scientists) silence on Greene’s challenge is that if the scientific orthodoxy is literally comprehended by the heterodoxy, then

⁹⁵ *Ibid.*, p. 41.

⁹⁶ *Ibid.*, p. 61.

⁹⁷ *Ibid.*, p. 61.

science has to let metaphysics into the heart of its scientific method and take seriously the challenge that the observed cannot be separated from the observer. This was a step too far for Waddington in 1923 at Clifton, in 1931 in his abstraction essay, and in 1941 in *The Scientific Attitude*. Far from retreating, it could be argued that Waddington is holding the line that he has maintained since his early school days.

At Serbelloni, Waddington affirmed that his metaphysics beliefs are consciously held and have affected the “types of problems I choose to ask, and the manner in which I tried to solve them.”⁹⁸ His choice to study a network of mutations interacting to affect the development of wing length, for example, is directly influenced by his Whiteheadian view that wing development is a concrescence of events, which he explicitly links to the channels of development (*chreodes*) in the epigenetic landscape. His choice of embryology as a context and his subsequent development of the epigenetic landscape were influenced by “two (or perhaps three) notions which infiltrated into my thinking at a very early stage, without much benefit of academic dignity, and which have remained there ever since.”⁹⁹ Waddington goes on to describe the world egg and the ouroboros as two of these ideas.

The world egg is a universal holistic metaphysical symbol of creation, a symbol of primordial chaos out of which the living world emerges.¹⁰⁰ For Carl Jung, it is a true symbol, attributed to the “collective unconscious,” the *prima materia*, containing the captive world-soul.¹⁰¹ The ouroboros, the symbol of the snake eating its tail, inscribed with the third subsidiary notion of the slogan, “ἐν το παν,” “hen to pan,” “the one to all,” equate to

⁹⁸ *Ibid.*, p. 72.

⁹⁹ *Ibid.*, p. 73.

¹⁰⁰ H. J. Sheppard, “Egg Symbolism in Alchemy,” *Ambix* 6, no. 3 (1958): 140–48.

¹⁰¹ C. G. Jung, *Psychology and Alchemy* (London: Routledge and Kegan Paul, 1968).

Whitehead's conception of "prehensions", the idea that "any one entity incorporates into itself in some sense all other entities in the universe."¹⁰² This reciprocity, Waddington firmly roots in cybernetic regulation.

These "highly poetic metaphysics," were later added to by the more "explicitly rationalised thinking" of Whitehead. This addition supports the argument of this paper that the alchemical symbols still exist in Whitehead's thinking, but he has "banished the magic" from them, abstracting them into the epigenetic landscape. The links between the world egg and Whitehead's events are clear in this rather complex and personal paragraph:

'Things' are essentially eggs – pregnant with God-knows-what. You look at them and they appear simply enough, with a bland definite shape, rather impenetrable. You glance away from it when you look back at what you find is that they turned into a fluffy yellow chick, actively running about and all set to get imprinted on you if you give it half chance. Unsettling, even perhaps a bit sinister. But one strand of Gnostic thought asserted that everything is like that.¹⁰³

To Whitehead, "things" do not exist – they are processes, actual occasions of experience, whose potentialities are "essentially infinite, undenumerable."¹⁰⁴ The realised potentialities are determined by the interaction of objects within the event and the regulatory influences of the prehensions without. So, the strand of gnostic thought that "*everything* is like that", suggests that Holmyard's alchemy was a prediction for Waddington's later acceptance of Whitehead. The "unsettling, slightly sinister" transformation of a tissue into a goal-directed organism, reinforces Waddington's unsentimental nature, which did not wear its "heart on its sleeve," and which had been strengthened by Clifton's boarding school life.¹⁰⁵

For Squier, the world egg is a powerful feminine symbol. Its abstraction into the epigenetic landscape is a loss, "mark[ing] the moment when theoretical biology withdrew not

¹⁰² Waddington, *Towards a Theoretical Biology* (ref. 6), p. 73.

¹⁰³ *Ibid.*, p. 73.

¹⁰⁴ *Ibid.*, p. 75.

¹⁰⁵ Robertson, "Conrad Hal Waddington" (ref. 18), p. [number?].

only from its metaphysical preoccupations but from its related, specifically sensuous and situated exploration of ontogeny.”¹⁰⁶

So, where in the epigenetic landscape are the world egg and the ouroboros? The potentiality of the world egg is distributed between the genome of the fertilised egg, the cytoplasm of the egg, and the external environment, each of which can influence how the genome is activated. The genome, in turn, influences the development of the cytoplasm and can change the environment external to the cell. The regulation is similarly distributed; Waddington’s research of the wing development of *Drosophila* showed that gene mutations were disrupting the developmental pathways leading to normal wings, forcing the development down different, rarely used channels. Likewise, an environmental change could redirect development along different channels to produce a different phenotype. Waddington showed this empirically with the cross-veinless phenotype, which is revealed by treating *Drosophila* larvae with temperature shocks; ether (ethoxyethane) vapour can induce the development of a double thorax (the bithorax phenotype).¹⁰⁷ Development across the epigenetic landscape can be shaped by the genome as it is by the environment.

Holmyard’s final legacy to the world was to teach the young Waddington about the philosophy and practice of the scientific method. Using Waddington’s own taxonomy of ideas, “general hypotheses” that will form the subject of experiments are always abstracted

¹⁰⁶ C. M. Squier, “The World Egg and the Ourorobos,” in *Scholar and Feminist Online* (2013), <http://sfonline.barnard.edu/life-un-ltd-feminism-bioscience-race/the-world-egg-and-the-ouroboros/>; Squier, *Epigenetic Landscapes* (ref. 79).

¹⁰⁷ C. H. Waddington, “Genetic Assimilation of an Acquired Character,” *Evolution* 7, no. 2 (1953): 118–26, C. H. Waddington, “Canalization of Development and the Inheritance of Acquired Characters,” *Nature* 150 (1942): 563–65

from the “meta-theories” which are “concerned with deciding which topics it is profitable to have theories about.”¹⁰⁸ Meta-theories, like the epigenetic landscape, are informed by metaphysics.

Waddington suggested to Marjorie Grene that he was “not a wholly orthodox mechanical materialist,” but neither was Holmyard, and their joint legacy, in terms of the epigenetic landscape, the journal *Endeavour*, and the nature of the science taught at Clifton, lives on.

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¹⁰⁸ Waddington, *Towards a Theoretical Biology* (ref. 6), p. 177.