Drawing as Epistemology for Morphology

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In Collaboration with Falmouth University.

This PhD thesis is dedicated to my grandmother Eileen (Eleanor) Teresa Donohue (1913-2006).

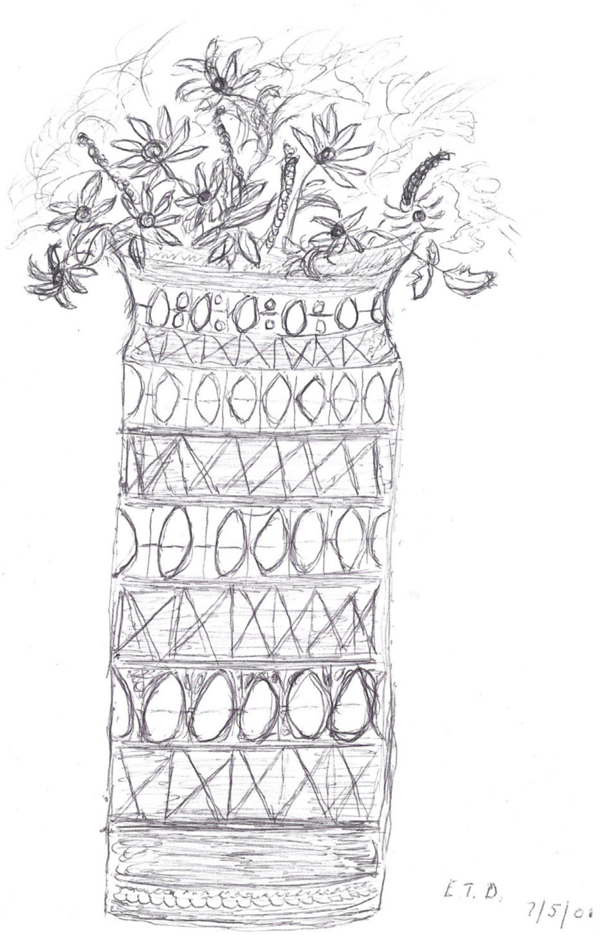

Figure 1.
DONOHUE, E.T. 'Flower-pot', 2001,
pen on paper.

Declaration

I declare that the thesis presented consists of 81,719 words.

I certify that the thesis I have presented for examination for the degree of Doctor of Philosophy is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified).

I warrant that this authorisation does not, to the best of my belief, infringe the rights of any third party.

Statement of conjoint work

I confirm that the second article in chapter three 'Drawing in Mathematics: from Inverse Vision to the Liberation of Form' was co-authored with Dr.Tom Coates, Prof.Alessio Corti and Dr.Dorothy Buck (Imperial College). Further, I confirm that Chapter Seven 'Mathematics and Art: notes from an artistic collaboration' was co-authored with Prof. Alessio Corti.

Publications

The thesis includes the following publications, all of the work for which has been carried out following my registration in the PhD program in the University of the Arts London:

ANDERSON, G. 2014a 'Endangered: A Study of Morphological Drawing in Zoological Taxonomy' *Leonardo*, 47(3), pp. 232–240.

ANDERSON, G., BUCK, D., COATES, T. and CORTI, A. 2015 'Drawing in Mathematics: From Inverse Vision to the Liberation of Form', *Leonardo*, 48 (5), pp. 439-448.

ANDERSON, G. and CORTI, A. 2015 'Notes from an Artistic Collaboration', in EMMER, M. and ABATE, M. (eds.) *Imagine Maths 4*. Unione Matematica Italiana; (1st edn), pp.72-82.

Further to these publications, the following material has been published, exhibited and disseminated in advance of the formal submission of this thesis:

ANDERSON, G. 2013a 'Art and science on the Isles of Scilly'. *NaturePlus* [Website], London: The Natural History Museum. Available at: http://www.nhm.ac.uk/natureplus/community/nature-live/field-work-with-nature-live/blog/2013/08/23/art-and-science-on-the-isles-of-scilly?fromGateway=true (Accessed: 22 July 2015)

ANDERSON, G. 2013b 'Day One: Weeding on the Isle of St Mary's' .*NaturePlus* [Website], London: The Natural History Museum. Available at: http://www.nhm.ac.uk/natureplus/community/nature-live/field-work-with-nature-live/blog/2013/08/29/field-work-day-1-weeding-on-st-marys [Accessed: 22 July 2015]

ANDERSON, G. 2013c 'Day Two: St Agnes Seaweed Biodiversity and Drawing Workshop' *NaturePlus* [Website],, London: The Natural History Museum. Available at: http://www.nhm.ac.uk/natureplus/community/nature-live/field-work-with-nature-live/blog/2013/08/30/day-2-st-agnes-seaweed-diversity-and-a-drawing-workshop [Accessed: 22 July 2015]

ANDERSON, G. 2013d 'Day Three: Entomology on the Isles of Scilly' *NaturePlus* [Website], London: The Natural History Museum. Available at: http://www.nhm.ac.uk/natureplus/community/nature-live/field-work-with-nature-live/blog/2013/09/02/day-3-entomology-on-the-isles-of-scilly[Accessed: 22 July 2015]

ANDERSON, G. 2013e 'Fieldwork methods in Art and Science' *NaturePlus* [Website],, London: The Natural History Museum. Available at: http://www.nhm.ac.uk/natureplus/community/nature-live/field-work-with-nature-live/blog/2013/09/06/fieldwork-methods-in-art-and-science [Accessed: 22 July 2015]

ANDERSON, G. 2013f *Isomorphology: An Introduction*. London: Super-Collider

ANDERSON, G. 2013g 'Rearranging the Natural World'. UCL Museums and Collections Blog. Available at: http://blogs.ucl.ac.uk/museums/2013/05/09/isomorphology/ [accessed 05/05/15]

ANDERSON, G. 2013h *Isomorphology*. EB and Flow Gallery, London.

ANDERSON, G. and BROAD, G. 2013 'Symmetry and Form in Nature' [video of talk]. Nature live, *NaturePlus* [Website], London: The Natural History Museum. Available at: https://vimeo.com/65225351exhibition [accessed 05/05/15]

ANDERSON, G. 2014a 'Endangered: A Study of Morphological Drawing in Zoological Taxonomy' *Leonardo*, 47(3), pp. 232–240.

ANDERSON, G. 2014b 'The Big Draw at the Natural History Museum'. Available at: http://www.thebigdraw.org/the-big-draw-at-the-natural-history-museum (Accessed: 7 July 2015)

ANDERSON, G and FREEBORN, A. 2014. 'Science and Art meet at the AMC' *NaturePlus* [Website], Available at: http://www.nhm.ac.uk/natureplus/blogs/behind-the-scenes/2014/10/29/science-and-art-meet-at-the-amc?fromGateway=true (Accessed: 7 July 2015)

ANDERSON, G. 2015a *Isomorphology*. Cornwall: Atlantic Press

ANDERSON, G. 2015b 'Isomorphology talk at the Art and Science of Modern Systematics Symposium', Hannover, Volkswagen Foundation. Available at: https://soundcloud.com/isomorphology/isomorphology-talk-at-the-art-and-science-of-modern-systematics-symposium-hannover-june-2015 [accessed 05/05/15]

ANDERSON, G. 2015c *Cornwall Morphology and Drawing Centre* [Website Archive]. Available at: www.cmadc.co.uk (accessed September 2015).

ANDERSON, G. and CORTI, A. 2014. 'Notes from an Artistic Collaboration' Veneto Institute of Science, Literature and Art. Available at: https://www.youtube.com/watch?list=PLfcFPNXyAOqatuGE3E9ZqwVqt10iel3Jy&v=mv2xbnlnWho [accessed 05/05/15].

ANDERSON, G. and HATHERHILL, Chris, 2013 'Isomorphology' exhibition talk with Super/Collider Director Chris Hatherhill', London, EB and Flow Gallery. Available at: https://soundcloud.com/isomorphology/talk-gemma-anderson-super [accessed 05/05/15].

ANDERSON, G. and ZINECKER, Johanna, 2013 'Riddles of Form' exhibition talk with curator Johanna Zinecker', Berlin: Thore Krietmeyer Gallery. Available at: https://soundcloud.com/isomorphology/johanna-berlinwma [accessed 05/05/15].

Solo Exhibitions

ANDERSON, 2016. 'Drawn Investigations from Art and Science', Naughton Gallery, Belfast.

ANDERSON, 2013 – 2014. 'Isomorphology: Riddles of Form', Galerie Thore Krietemeyer, Berlin.

ANDERSON, 2013. 'Isomorphology', EB & Flow Gallery, London.

ANDERSON, 2012. Imperial College research festival, exhibitor and presenter 2012 Research Festival Imperial College, London.

ANDERSON, 2012. '100 Years of Laue Mineral X-Rays', The Mineralogy Department, Natural History Museum, London

Group Exhibitions

2015 'Crooked Rain, Crooked Rain', Centre for Contemporary Art, Derry

2014 D'Arcy Thompson Art Fund, D'Arcy Thompson Museum, Dundee

2014 'Drawing Making: Making Drawing' The Drawing Room, London
2014 'Mapping Alternative Ulster', Ulster Museum, Belfast
2014 Golden Thread Gallery, Scope, New York
2013 'Coral', Manchester Museum, Manchester
2013 'Olaf Bastigkeit and Gemma Anderson', Galerie Thore Krietemeyer, Berlin
2013 'Drawn from structures', D'Arcy Thompson Museum, Dundee

Conference presentations, public talks and workshops

2016, Public talk at 'Drawn Investigations from Art and Science', Naughton Gallery, Belfast.
2016, Isomorphology Workshop at 'Drawn Investigations from Art and Science', Naughton Gallery, Belfast.
2016, Isomorphogenesis Workshop at 'Drawn Investigations from Art and Science', Naughton Gallery, Belfast.
2015 Cornwall Morphology and Drawing Centre, 'The Art and Science of Systematics', collaborative drawing workshop with zoological scientist Dr. Gavin Broad
2015 'The Art and Science of Modern Systematics' Interdisciplinary Symposium, Hannover, Germany, 23-27th June, Talk and Workshop
2015 Cornwall Morphology and Drawing Centre, Launch Event in collaboration with Colin French and Courtenay Smale
2015 Cornwall Morphology and Drawing Centre, 'Isomorphology of the Lizard', collaborative drawing workshop with botanical scientists Dr. Colin French
2015 Cornwall Morphology and Drawing Centre, ''Drawing in the Fourth Spatial Dimension', collaborative drawing workshop with mathematician Professor Alessio Corti
2015 Cornwall Morphology and Drawing Centre, 'Drawing the Six Crystal Systems', collaborative drawing workshop with mineralogist Courtenay Smale
2014 Guest Speaker, Panelist and Exhibitor, University Art Association Canada Conference, Ontario College of Art and Design, Toronto.
2014 Invited Speaker, International Word and Image Association Conference, Dundee University, Dundee.
2014 'Isomorphology' Drawing Research Network Conference, Columbia University, New York
2014 Public talk and Seminar with BFA students at Ontario College of Art and Design
2014 Postgraduate Lecture, Ontario College of Art and Design, Toronto, Canada
2014 Invited Speaker, International Word and Image Association Conference, Dundee University, Dundee.

2014 Big Draw Event, 'FormSynth and Isomorphogenesis' Gemma Anderson and William Latham, The Natural History Museum, London.
2014 Invited Speaker, Egenis Research Centre, Exeter University
2014 Invited Speaker, Mathematics and Culture Conference, Venice
2014 Invited Speaker, International Association of Word and Image Studies Conference, Dundee
2014 Drawing Making: Making Drawing, Creative Morphology Workshop, The Drawing Room, London
2013 Artists Talk with Mathematicians Tom Coates and Dorothy Buck, Berloni Gallery London
2013 Invited Speaker, Drawing Research Network Conference, Metropolitan Museum of Art, New York City
2013 Invited Guest Speaker, Das Interdisziplinäre Labor – Bild Wissen Gestaltung / Image Knowledge Gestaltung. An interdisciplinary Laboratory, Cluster of Excellence, Humboldt-Universität, Berlin
2013 Observation and Morphology Drawing Workshop (for scientists), Natural History Museum London and Natural History Museum Berlin
2013 Artists Talk: Gemma Anderson In conversation with Johanna Zinecker (Humboldt University), Galerie Thore Krietemeyer, Berlin
2013 'Creative Morphology and Drawing', Workshop, Natural History Museum, London
2013 'Artistic Research in a Scientific Context', Science Uncovered Festival, Natural History Museum, London
2013 ''Goethe and Morphology- Drawing Methods' Natural History Museum, Berlin
2013 'Nature Live', Natural History Museum, London
2013 Isomorphology Workshop, Grant Museum, University College London
2012 Keynote: 'Drawing in Mathematics: Geometry, Reasoning, Language and Form' with Tom Coates (Geometer, Imperial College), Dorothy Buck (Topologist, Imperial College) and Alessio Corti (Geometer, Imperial College) at 'Drawing in STEAM' Conference, Wimbledon College of Art, 2012
2012 'Endangered: A study of the declining practice of morphological drawing in Zoological Taxonomy', 'Drawing Out' conference, University of the Arts, London
2012 'Resemblance perception as epistemic drawing process: Rashleigh's Mineral Nicknames', Drawing Research Network conference, Loughborough University
2012 New Independent School of Philosophy (NISP), University College Falmouth, 'Drawing and Bioscience', Presenter.

Acknowledgements

This work has been made possible through the help and support of numerous colleagues and friends.

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A special thanks to Elizabeth Wragg at Falmouth University, whose continued support encouraged the writing of this thesis at every stage. I would also like acknowledge the exceptional work of Cherry Dishington at Falmouth University Library, who sourced what seemed like endless interlibrary loans for this research.

Thanks to each scientist and curator at the Natural History Museum who supported this research, of which there are too many to mention here. A special thanks to Gavin Broad, Peter Tandy and Clare Valentine who took exceptional interest in assisting with the artistic practice at the NHM, which often involved challenging negotiations.

I thank Tom Coates, Alessio Corti and Dorothy Buck, for welcoming me into the mathematics department at Imperial College and for meaningful and ongoing collaborations. I look forward to future projects together. I also gratefully acknowledge and thank Simon Bird, Alexander Kasprzyk, Andrew MacPherson, Fiona Sperryn, Adam Stringer, and Andrzej Stasiak for valuable technical assistance.

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Contents

Abstract

This thesis presents drawing as epistemology for morphology through the development and dissemination of drawing practices that extend understanding of, and engagement with, the diversity of natural form. The interpretation of the term 'morphology' is based on Goethe's original concept (1792) of morphology as the 'study of form and formative process'. This research is situated in the context of the emerging fields of 'Drawing Research', 'Art/Science' and the cross-disciplinary domain where contemporary art practice and education intersect (the 'educational turn'). Led by drawing practice, the methodology encompasses a set of experimental approaches including interdisciplinary collaboration, museum collection study, workshop design, and exhibition making. This mixed method approach is conducted within the context of scientific institutions like the Natural History Museum and Imperial College, London to address two research questions. The first asks what contribution an artist can make, especially through drawing in collaboration with scientific practices and instrumentation, on representations and forms of analysis and interpretation that could lead to new understandings of morphology (animal, mineral, vegetable) for both artists and scientists? The second asks what shared morphological characteristics (form and symmetry) of animal, mineral and vegetable species can be identified and represented through the process and object of drawing and whether this research can develop an extra-scientific model of classification that is complementary to the scientific approach?

This enquiry has contributed to the development of two interlinked bodies of artistic research (and two new terms and practices) 'Isomorphology': the observational study of the shared forms and symmetries of animal, mineral and vegetable species, and 'Isomorphogenesis': the systematic representation of dynamic form through drawing. These practices have been shared with artists, natural scientists, students and the general public through participatory workshops, conferences, publications and exhibitions. Early chapters provide examples of drawing as a 'way of knowing morphology' in the context of contemporary natural science and mathematics (empirical and conceptual), which are followed by a narrative of the development of 'drawing as a way of knowing' in my own artistic practice through the Isomorphology study. The later chapters then discuss the evolution of the Isomorphology concept and practice, as a shift from observation to abstraction first in the 'Goethe method' and later in the conceptual study of the dynamic nature of form 'Isomorphogenesis' (adding the 4th dimension of time). These chapters build a narrative, towards drawing as epistemology for a dynamic, process-oriented morphology. This developmental series of empirical and conceptual drawing practice and theory brings my work with natural science (empirical) and mathematics (conceptual) together. The final chapter documents how this research is then shared as an experimental educational model through the Cornwall Morphology and Drawing Centre project.

Chapter One

Introduction

This thesis focuses on the twin themes of morphology and drawing through an exploration of intuitive and experimental drawing methodologies. The aim is to develop and share new ways in which drawing practice can enhance morphological insight, specifically within the contexts of the natural sciences, mathematics and art. Central to this study is Goethe's concept of morphology, which he defined in 1792 as 'the study of form and formative process' (Goethe, 1996). In this research I also extend Goethe's concept of morphology to unite contemporary art with natural science and mathematics in the study of form by encompassing differing methods and approaches. Interdisciplinary collaborations with natural scientists and mathematicians have informed the development of my drawing methods, which are designed to explore morphological questions emerging from both artistic and scientific study.

Shaping this study throughout are the research questions:

> 1. What contribution can an artist make - especially through drawing effected in collaboration with scientific practices and instrumentation representationally, analytically, and in terms of interpretation - to achieving a new understanding of morphology (animal, mineral, vegetable) for both artists and scientists?

As elaborated throughout this thesis, morphology as the study of form provides a meeting point for art and science, but lacks a clear paradigm of artistic approach for study. The next question emerged out of my artistic practice, which studies morphological resemblances between otherwise unrelated objects of the natural world.

> 2. What shared morphological characteristics (form and symmetry) of animal, mineral and vegetable species can be identified, known and represented through the process and object of drawing? And how can this research develop an extra-scientific model of classification which is complementary to the scientific approach?

This question seeks morphological similarities, not differences and builds on the foundation of my own study of resemblance. Both of these questions are unpacked and discussed further in the methodology, which follows this introduction.

Drawing is used to address these questions and, through the process of this practice-based enquiry, drawing methods emerge that allow artistic and scientific work to converge and then to diverge. Although led by drawing practice, this research develops in parallel with and is propelled forward by reading, practical investigations and scientific collaborative work – the nature of which is outlined in the methodology. Much of this research practice has taken place at the Natural History Museum, London (NHM) where working relationships with scientists and curators have been developed to support this research which draws directly from the museum's collections[1]. An important part of my role as artist and researcher is establishing and developing a number of necessary collaborative relationships.

Research Context

There is no separate literature review here because the influence of reading is woven through each chapter in relation to practice. This research builds on the interplay between conceptual and contextual issues arising from the literature and the actual practice I carried out as an artist. Thus, rather than separating the literature and context of my research from the practice, the two remain interwoven, just as they were in the course of my research, where the theory generated practical questions and the practice responded by generating new conceptual questions. Both aspects fold into each other and converge in an articulation of theory and practice, which I try to maintain in the written component of my research. A broader characterisation of the research context brings it in line with three major emerging fields in practice-based research: Drawing research, Art/Science and the Educational Turn.

Drawing Research

Drawing adds to the repertoire of possible forms of knowing (Daston, 2010)
Drawing research has emerged in recent years, through a number of exhibitions, conferences and publications, as an active strand of artistic and ontological interest. In this section I will outline some of the developments and position my work in the context of the emerging field.

In *Writing on Drawing – essays on drawing practice and research* (2012) Steve Garner argues for the value of drawing research to communities beyond the art world,

1 There were many challenges in setting up this study. It began with negotiating drawing appointments in scientific labs or offices and then negotiating a designated visitor space and then a designated lab space. This process often depended on the good will of individuals and chance meetings, but was led in development by my own vision of the collaborative relationship.

namely the scientific and cultural: 'drawing research presents a powerful opportunity to demonstrate the ability to generate new knowledge about the visual and to communicate this through the visual' (Garner, 2012:15). Garner's view, like John Berger in *Ways of Seeing* (Berger, 2009), challenges the assumption of the supremacy of the written word in visual research. Conceived as a form of drawing research, this PhD project is distinctive in that it positions drawing in relation to Goethe's concept of morphology and applies the drawing methodology within an artistic and a scientific context, offering new methods for morphological study to both. This research therefore contributes to the understanding of drawing as a way of knowing, specifically as a collaborative tool in relation to practices of the established scientific disciplines of natural sciences and mathematics, and has been recognised by the Campaign for Drawing[2] as research that successfully uses 'drawing as a way of bringing art and science together' (Campaign for Drawing, 2015).

This 'drawing research' is different from the work of Petherbridge (2009) and Gombrich (1996), who place drawing in an art historical context, and from the research of Tversky and Tchalenko (2009) who offer a psychological enquiry about the drawing process and also from the educational and developmental aspects of drawing as explored by Greene and Willats (1984). As a practice based study, it is also distinctive from Wittmann's historical perspective on the epistemological value of drawing in science.

The emerging field of 'drawing research' can currently be understood through the two main themes: 'drawing and cognition' (THINKING THROUGH DRAWING, 2014) and 'drawing across disciplines' (TRACEY, 2015), in which there has been more interest in drawing as a method of inquiry and methodology both within the arts and in other disciplines. An important part of the development of the field of drawing research is the publication of practice-based PhDs[3] in this field, which have established drawing as a research method[4].

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2 The Campaign for Drawing is an independent charity, which raises the profile of drawing as a tool for thought, creativity, social and cultural engagement.

3 Maryclare Foa's PhD Research emphasised drawing practice as phenomenology, a theme also explored by Deborah Harty and Patricia Cain (http://www.patriciacain.com/phd-thesis-abstract/). Joe Graham's PhD research focused on aspects of the epistemic qualities of drawing and Michelle Fava's on drawing and cognition. Other PhD's of interest include: Claude Heath, Antony Auerbach and Irene Kopelman's 'The Molyneux Problem', 2007-2011.

4 Sarah Casey has developed a practice-based methodology which integrates procedures from medicine and conservation sciences into a drawing practice investigating notions of delicacy and preservation. Neil Hodgson uses drawing to document and transcribe improvised and ad-hoc structures (sheds, lock-ups, pigeon coops) found in marginal environments at, or beyond, the 'pale' of cities. Osman Ahmed, who using drawing, interviews and fieldwork, seeks to catalogue and communicate experiences of fear, flight and displacement among Iraqi Kurds. These research students form the basis of a research group, provisionally titled Drawing's Mobility.

To situate this research within the specific emerging field of 'drawing research' I have contributed to activity within the field[5] through presentations at the Drawing Research Network (DRN) Conferences, Thinking Through Drawing (TTD) symposiums[6] in London and New York and through exhibiting at the Drawing Room, in London and the exhibition and symposium A Call for Drawings[7] in MaHKU Utrecht; HKU University of the Arts Utrecht and The Slade School of Art, University College London. This research has also been presented at conferences of philosophy, word and image and history of science and of art[8], as well as scientific publications such as *Imagine Maths 4* (Anderson and Corti, 2015) thus demonstrating its value and interest to communities beyond the art world.

Drawing is also growing as a subject in its own right, with BA Drawing courses now being offered in the UK by Camberwell[9] (UAL) and Falmouth University, where I am currently Associate Lecturer. The Royal College of Art has a designated Drawing Studio (where I am currently a visiting lecturer), with its own programme, open to all students, which sustains the previous Centre for Drawing Research[10], the first doctoral programme in drawing in the UK and which ran an extensive course of drawing workshops and open lectures for the whole college. In line with this development, drawing research groups have emerged, most notably the 'International Drawing Research Institute' (IDRI), which is a consortium created to advance research into and through the discipline of drawing. The institute promotes the seminal role of drawing within art, design, architecture and interdisciplinary visual discourse across any or all of the disciplines of higher education. The Institute comprises three founding members: The College of Fine Arts, UNSW in Sydney (COFA), The China Central Academy of Fine Arts in Beijing (CAFA), Glasgow School of Art (GSA) and the International Drawing Research Institute (IDRI).

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5 With this field come drawing researchers, some more established like Deanna Petherbridge, Anita Taylor and Tanya Kovats and Catherine De Zegher, who organised a Tate Britain symposium – 'With A Single Mark (De Zegher, 2006) and recently published a new book On Line, Drawing through the Twentieth Century'(De Zegher, 2010). This encourages the hybridizing of disciplines, drawing, standing independently answers those demands for interaction while refusing homogenisation and manipulation".22
This more recent drawing research builds on the historical work of Ruskin, Berger and others who wrote about aspects of drawing as a way of knowing before the field of 'drawing research' came into existence.

6 I delivered a keynote lecture, with Tom Coates: On Drawing and Mathematics in 2013

7 Call for Drawings, BAK, Lange Nieuwstraat 4, 24 June - 12 July, 2015

8 Details of publications in Preface.

9 Led by artist and researcher Kelly Chorpening

10 Established by Deanna Petherbridge who was Professor of Drawing at the Royal College of Art from 1995 to 2001.

Drawing Out (active since 2010) is another research group at the University of the Arts London, while other groups continue to emerge, most recently Falmouth University's School of Art Drawing Forum, Spring 2015. Falmouth University have also supported this drawing research project through funding 'The Cornwall Morphology and Drawing Centre' which I established in 2014 as a designated research and learning space for drawing in collaboration with the natural sciences and mathematics[11].

Drawing has also become a focus for contemporary art exhibitions. For example, the recent exhibition and symposium 'A Call for Drawings' is a project, exhibition and symposium curated by Klaas Hoek that selects drawings[12] from artists, scientists and other professionals for an interdisciplinary research project investigating the role of visual thinking in cognitive and creative processes. This 'call for drawings' can be understood as analogous to the practice in the academic world of 'a call for papers', as such recognising drawing as an epistemological tool in scientific and technological disciplines through sketches, maps, drafts, diagrams and other kinds of drawings. Hoek sees drawing as essential to the understanding of problems and the communication of thoughts towards their solutions, saying:

> When probing into the unknown, drawing is an ideal tool because drawing is thinking, pointing; it makes things present and puts them at a distance, it is a mode of inquiry. Drawing can represent the seen and present the unseen, the known and the unknown (A Call for Drawings, 2015).

Like this drawing research, A Call for Drawings aims to demonstrate and share the drawing methodologies of artists, scientists and other specialists to establish a common ground between diverse disciplines, and to discover correspondences between the creative processes in different fields of activity in order to share knowledge and to collaborate.

The Jerwood Drawing Prize[13] has been exhibiting the diversity of contemporary drawing in London since 1994 and provided inspiration for the more dynamic workshop and exhibition programme *Drawing Making: Making Drawing* (2014), which

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11 The CMADC studio developed a physical, conceptual and practical field specifically for this research.
12 My drawing of a four-dimensional tree, as documented in Imagine Maths 4 (Anderson and Corti, 2015) was selected as part of this exhibition.
13 In 2010, I observed the selection process for the Jerwood Drawing Prize as part of my role as Jerwood artist in residence.

included some of the UK's leading artists working with drawing practice, such as Cornelia Parker, Tim Knowles, Claude Heath and Dryden Goodwin, and to which I also contributed[14]. *Drawing Making: Making Drawing* was held at The Drawing Room, London, the UK's largest drawing-centred exhibitor and publisher specifically focused on drawing[15]. The Drawing Room provides a regular curated exhibitions programme including experimental themes, such as 'Graphology' (2012), which explored drawing techniques that translate direct experience into different forms of systematised representation, between the trace and the sign and between writing and drawing[16]. Other drawing-focused centres and projects include the Drawing Centre in New York, which is distinctive as a museum and the only US non-profit space solely for drawing exhibitions[17], the Centre for Recent Drawing London and the Cornwall Morphology and Drawing Centre (CMADC, Helston, Cornwall) and the Centre for Drawing in Wimbledon (which has been inactive since 2011).

Journals investigating drawing have also emerged over recent years, most recently Drawing Research Theory and Practice (DRTP) (Intellect Ltd) which published its first volume in 2015[18]. Key topics explored by DRTP include drawing as an experimental practice, as research, as representation and/or documentation, drawing as process or as performance, and drawing as an interdisciplinary practice, while taking into account the diversity of its practical, theoretical and physical expressions. The first issue of DRTP includes a profile of my work by Kenna Hernly 'Drawing the real and the unknown' (Hernly, 2015b).

A more established drawing research journal is the TRACEY[19] online *Journal of Drawing and Visualisation Research*. TRACEY has inspired a series of Drawing Research Network proceedings and publications that have formed a separate peer-reviewed edition[20] as well as the proceedings publication[21] in 2012.

14 https://drawingroom.org.uk/events/workshop-2-drawing-making-making-drawing-with-gemma-anderson where my work was included, both as exhibited artwork and as workshop, talk and panel/discussion format - quote from TIT review.

15 Internationally, The Drawing Room is perhaps paralleled only by the Drawing Centre New York, which also exhibits and publishes drawing.

16 While Drawology explored drawing's ability to record both its own making and the movement of the thoughts and body of the drawer - http://www.boningtongallery.co.uk/exhibitions/drawology

17 Of particular interest have been 3 x Abstraction, New Methods of Drawing by Emma Kunz, Hilma af Klint, and Agnes Martin,(NYC) and in Berlin Systems Drawing (Schering 2013/14),

18 The first volume features an article about the Cornwall Morphology and Drawing Centre, authored by Tate curator Kenna Hernly

19 TRACEY was started at Loughborough while Steve Garner was in charge of DRN, after which Loughborough have managed the journal. Current directors include Deborah Harty and Simon Downs.

20 Which published 'Drawing and Reasoning' (Anderson and Coates 2014)

21 An example of a publication which emerged through the DRN is Hyperdrawing: Beyond the Lines of

Significant recent publications include *Writing on Drawing, essays on drawing practice and research* (Garner, 2008), Katharine Stout's *Contemporary Drawing: From the 1960's to now* (Stout, 2014), and Mick Maslen and Jack Southern's *Drawing Projects*[22] (2012). Alongside these major book publications, other artists' publications include Aeurbach's *Grapheus Was Here* (2011), featured in Nikolaus Gansterer's publication project *Drawing A Hypothesis: Figures of Thought* (Gansterer, 2011: 65–76), which explores the ontological basis of forms of visualisation and the development of the diagrammatic perspective and its use in contemporary art, science and theory. Based on a discursive analysis of found figures with the artist's own diagrammatic maps and models, Gansterer collaborated with artists and scientists to reveal drawing as a medium of research, which enables the emergence of new narratives and ideas[23]. Another artist publication *Anchor*, by Joe Graham (2015) curates the drawings of a number of contemporary artists[24] on the theme of 'outline'.

The Campaign for Drawing (CFD) is a charity founded in 2000 that aims to promote drawing activity and has recognised the 'drawing research' activity of this PhD project, including The Cornwall Morphology and Drawing Centre, through their website and social media. The CFD started the Big Draw in 2000, which has since grown into an annual festival of drawing[25] and delivers drawing events and workshops all over the UK. In 2014 I designed and delivered 'Experimental observational drawing workshop - Isomorphogenesis' at the Natural History Museum as part of the annual Big Draw festival. This workshop, which I led in collaboration with William Latham, was featured on the CFD website (Anderson, 2014).

Contemporary Art, in which authors and artists come together to explore the potential of drawing in contemporary art theory and practice. This publication follows Drawing Now: Between the Lines of Contemporary Art, (2007) by Phil Sawdon and Russell Marshall who are two of the current directors of TRACEY. Through four essays and images from 33 international artists Hyperdrawing explores the boundaries of the hyperdrawing space, investigating drawings that use traditional materials or subjects whilst also pushing beyond the traditional, employing sound, light, time, space and technology and recognising the opportunities inherent in the essential versatility of drawing and a 'conception of hyperdrawing as techne, a productive space no longer limited by spatial boundaries'.`

22 In which I am one of the featured artists

23 The S.M.A.K. gallery in Gent, Belgium, recently invited Nikolaus Gansterer to develop a drawing based in situ live performance for the exhibition "THE BOTTOM LINE" which samples the breadth of drawing in contemporary art. My own recent artist's book Isomorphology was inspired by Gansterer's drawing research project.

24 My drawings are included in this publications alongside Claude Heath, Virginia Verran and others.

25 The international celebration of drawing has grown from one day in October 2000 in the UK to an annual month-long festival of drawing across the world. The first Big Draw in 2000 attracted 180 partner organisations. By October 2011, the number had risen to 1,300, with over 260,000 people participating.

Art/Science and Interdisciplinarity

In recent years there has been a growing culture of 'Art/Science' or 'SciArt' in the UK, largely related to the SciArt programme, which emerged in the mid-1990s and was funded by the Wellcome Trust (Wellcome Trust 1999). The SciArt programme coincided with an emergent trend towards the breaking down of disciplinary boundaries, both within and across the arts and the sciences, and a move towards interdisciplinary collaboration, which encouraged flexibility and open-endedness. The SciArt programme describes the assumptions on which the two cultures of art and science work as profoundly alien to each other; scientists are perceived as more likely to work according to a set of axioms for/against some hypothesis and are nominally bound by the scientific method, whereas artists are generally perceived to have more freedom to explore unconventional questions and critique the media that they are using.

As the SciArt programme came to an end in 2005, the broader Art/Science[26] movement was defended and illustrated by *Leonardo* - the journal itself as well as the creative and institutional network that the journal's editor built around it. The recent book *Art, Science, and Cultural Understanding* (2014) demonstrates that a real dialogue is now possible between art and science, partly because scientists themselves have become more aware of issues and problems, such as the limitations of truth systems or objectivity (Wilson et al, 2014). The Wellcome Trust now supports Art/Science projects through its funding stream 'Arts Awards[27]' (Arts Awards, Wellcome Trust), under the condition that the art engages with biomedical science, while the Leverhulme Trust (Artist in Residence Grants)[28] programme offers funding for an artist to work within a university department that does not usually include artistic activity, for example my residency at Imperial College London, 2012. Organisations and residencies have also developed to foster Art/Science practices such as the Arts Catalyst and Super-Collider[29], which are based in London[30], while other groups operate in America[31], Australia[32] and

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26 An interesting development of the 'Art/Science' genre is the more recent 'Dev-Art' trend, represented through artworks such as William Latham's creative computational work 'Mutator' in the 'Digital Evolution' show at the Barbican 2014.

27 I received a Wellcome Trust arts award of £30,000 in 2009 for the project 'Portraits: Patients and Psychiatrists'

28 In which I took part in 2012 through an 'Artist in Residence' award with Imperial College Mathematics department.

29 The first edition of Isomorphology was published with Super-Collider in 2013

30 Other active Art/Science spaces in London include the Cube Shoreditch and Kinectica are based in London

31 For example 'The Laboratory' at Harvard University http://thelaboratory.harvard.edu/concept/artscience/, and Bio Hackers New York

32 Including: C-Lab: Art & Science Studio Lab in London; Laura Cinti & Howard Boland, School of Visual Arts New York: Bio Art Lab http://bioart.sva.edu/, Art Research Center University of California at Berkeley, http://arts.berkeley.edu/, SymbioticA, University of Western Australia

Europe[33]. My project belongs to this 'Art/Science' culture, as research that contributes drawing methods to enable artistic and scientific work to converge and then to diverge again, to the extent that the distinction between artistic and scientific practice blurs and therefore transcends the boundaries associated with the two 'cultures'.

On the back of these developments, Art/Science has emerged as a popular theme in contemporary art[34]. GV Art gallery is a hub for collaborations between artists and scientists, as seen in the 2011 exhibition *Art & Science: Merging Art and Science to Make a Revolutionary New Art Movement*, exhibiting artists such as Oron Catts and Annie Catrell[35] accompanied by a panel discussion moderated by Arthur Miller[36]. The main theme for this exhibition was a discussion of whether art and science were converging/hybridizing to form a 'third culture' (as proposed by Arthur Miller in his book *Colliding Worlds*). Art/Science has also been represented within university[37] and museum exhibitions, for example the current workshop and exhibition *On the Edge: Artists in Dialogue with the Humboldt University Collections* at the Tieranatomisches Theater (June 3rd – September 12th, 2015) is exhibiting seven international artists who have investigated the unstable status of objects between utility and historical value and explore the migration between collection and exhibition space. This exhibition and workshop acts on the assumption that exhibitions produce knowledge by aesthetic means. An artist and academic whose career reflects many of the practical realities and challenges of interdisciplinarity and working with museums is Martha Fleming[38].

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33 Vienna- Universität für angewandte Kunst Wien, Master of Art & Science. The objective of the Art & Science master's degree programme is to investigate the relationships between different artistic and scientific representational cultures and their respective cognitive and research methods. An inter- and trans- disciplinary approach and project-oriented education should stimulate interaction between model and theory construction and the application of methods, particularly in the arts and sciences. Also see Collide@CE Available at: http://arts.web.cern.ch/collide and Ars Electronica (Available at: http://www.aec.at/news/).

34 For example: the interdisciplinary and collaborative work of Mark Dion (Tate Thames project), Katie Patterson who was artist in residence at the Wellcome Trust Sangers Institute 2013, Christine Borland's medical project which explored human experience of medical science and the 'humanizing' of clinical science, Susan Hiller's Ten Months (1977-9) which showed photographs of her pregnant belly corresponding to lunar months and Cornelia Parker's collaboration with physicist Sir Konstantin Novoselov, who won the Nobel prize for his groundbreaking work on graphene to create a breath activated switch which triggers a meteor shower (2014)

35 Cattrell's practice as an artist is at times informed by working with specialists in neuroscience, meteorology, engineering, psychiatry and the history of science. This cross-disciplinary approach has enabled her to learn in depth about these fields and exposed her to cutting-edge research. She is particularly interested in the synthesis of art, science and the poetic, as seen in the Cape Farewell project (Tonkin, 2006)

36 Arthur Miller examines the histories of scientists and artists towards a theory of cognitive science for creative thinking. He is author of 'Colliding Worlds: how cutting edge science is redefining contemporary art'

37 A pioneer of Art/Science collaborations in the UK in the mid-1990's through commissioned projects was the Laboratory at the Ruskin School of Art at Oxford University, set up by curator Paul Bonaventura.

38 Martha Fleming runs the PhD Museum Programme at the University of Reading

Her exhibition *Atomism & Animism* at the Science Museum London (1999), explored the aesthetic methods of 'formal analysis and isomorphic comparison, juxtaposition of scale and of dimensions, puncturing realism and creating alternative narrative scenarios, rupturing received meaning through insertion and intervention in existent displays' (Fleming, 2015) revealing a disruption that relates to John Dupré's concept of *Promiscuous Realism* (Dupré, 1995) through an interdisciplinary approach.

This research has observed, adopted, adapted, appropriated, intervened and critiqued the non-art disciplines of the life sciences (especially morphology) and mathematics in both practice and theory for the purpose of furthering an artistic practice that offers new methods and analogies back to science. Although the Art/Science Movement is understood as a contemporary movement in art and in education[39], it has a history. This research draws more directly from the work of Paul Klee[40], an artist and teacher at the Bauhaus School, and Goethe, poet, morphologist and statesman, both of whom pioneered an interdisciplinary approach through the study of natural form. The contemporary notion of 'Art/Science' can be regarded as a rediscovery of an approach that is not in itself new but rather one that many, like Goethe and Klee[41], have practised before. Elkins (2009) recognises only a few contemporary artists[42] as effectively bridging the sciences and art, although this survey of art/science practice adds more examples to this short list.

An important characteristic of contemporary Art/Science culture is the collaborative nature of this field. Collaborative or 'post-disciplinary practice' has characterised contemporary art since the late 1960s. Perhaps the most obvious example being the Artists' Placement Group (APG, 1966) founded in 1966 by the artist couple Barbara Steveni and John Latham (Eleey, 2007) to integrate artists into businesses and corporations around Britain. The project was based on the belief that artists could have a positive effect on industry through their creativity and fresh perspective[43]. The APG

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39 Central Saint Martins School of Art and Design (UAL) launched the first Masters Degree in Art and Science in 2011, and has it's own Chair of Art & Science, Rob Kesseller

40 Other artists who have adopted phenomenological approaches and phenomenological testing of the natural world are those from the Biomorphism movement (Jennifer Mundy) Arp etc, the Swedish artist Hilma af Klimt, Peter Lanyon, Naum Gabo, Henry Moore and Charles Burchfield whose transcendental watercolours have inspired aspects of the palette of Isomorphogenesis.

41 A detailed account of the relationship between Klee's study of the dynamic nature of form and Goethe's conception of morphology in relation to this research can be found in Chapter Five and Six.

42 Such as Dorothea Rockburne, Eduardo Kac and Vija Celmins

43 Steveni felt that artists should be inside factories, working in context with systems of production rather than with the industrial residues of these processes, as Danial Spoerri and Robert Filliou were at the time, instead of pulling the

located the artist and the artwork out in the world[44], in a non-art or 'other' context, an idea summarised by Robert Rauschenberg's proposition outlined in a show at the Kunsthalle Dusseldorf in 1970, that 'the context is half the work'.

Art/Science dialogues which have developed since the 1960s in the UK still provide an interesting relation to the idea of the 'placement', now understood as the 'residency': for example William Latham's invitation to work with IBM in the mid-1980s. More recent examples include artist residencies at the Science Museum: Conrad Shawcross (2009-2011) who explored subjects that lie on the borders of geometry and philosophy, physics and metaphysics, and Fleming (1996 to 1999) who gave the lecture *Paradigm & Diagram: How Artists Think Science* (Fleming, 1996), and produced Open Book (1996) for the Science Museum and the Dulwich Picture Gallery. Fleming describes the nature of an artist's position within an 'other' context as creating a tension: 'on the one hand the artist has a modest, non-disruptive presence and on the other – a strong motivation for the artist being there is to generate change which often arises out of disruption, conflict or controversial/challenging existing ideas' (Fleming, 2015).

My own artistic research at the Natural History Museum (NHM) during this project can be understood as a form of 'placement' or residency, which resonates with those of the APG and of contemporary Art/Science culture. My artistic approach supports and enhances as well as challenges scientific convention, opening up a dialogue and exchange rather than an opposing or strictly challenging position. This artistic research at the NHM was unusual; although there are many artists working from the NHM's collections (on an appointment basis or working from the galleries), I was given a research pass, access to collections and a desk space in the Sackler Imaging Lab in the Darwin Centre. My artistic research became embedded in a lab where I was visible both to the public (through the Darwin Centre Cocoon) and to scientists in the lab and passing through.

This placement of artistic research within a lab was a structure that did not previously exist at the NHM (although there had been previous formal Artist in Residence programmes led by Bergit Arends and it has since been repeated as a model in the Olson lab, based on my example). My research performed an intervention with the

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audience and the context into the artwork,

44 In 1974, George Levantis was placed aboard three different shipping vessels and described the open brief of APG as inspirational: 'the undefined nature of my position proved to be the source of my ideas'.

museum collections and research culture, and therefore became an active, even radical agency within the NHM. This research, operated as modest and non-disruptive, while being driven by a motivation to challenge and critique scientific paradigms, especially those of classification. I had numerous meetings and conversations with curators and scientists and spent a significant amount of time drawing and viewing collections and handling specimens, which provided an opportunity to ask questions and offer different viewpoints for discussion. Martha Fleming recognises the difficulty in creating this kind of interjection into such an institution, pointing out:

> Examples of artists actually working directly with existent collections inside the logic of individual museums, and making this the very subject of their inquiry from within are very rare. This sort of investigation is the kind of project that always points out of its apparently hermetic specificity to become epistemological in nature. It is an activity for which one must have stamina, sustained vision, and highly developed diplomatic as well as intellectual tools. It does not so much differ from curatorial practice as extend it by bending its laws to breaking point; in fact, bending them round so that they face each other and form a question mark as much about themselves as about the entire practice of collection and display (Fleming, 2004).

This way of working can be understood in relation to what are now well-established artistic strategies; for example UK-based artist Christine Borland has developed a number of collaborations with scientists. In Borland's artistic research, collaboration provides a platform for questions about 'scientific fact' and an opportunity to merge the materials of her art with the media of new technologies. In this way, Borland's work links with the contemporary American artist Mark Dion, whose practice reflects different ways of understanding the world. He says:

> Scientists and artist often seem to occupy the same job, which is to describe and understand the world around us, however they have a remarkably different set of tools with which to accomplish this task. Science can be very good at discerning what the world is, however art can help us figure how we feel, think and cope with that (Mark Dion 2013, personal communication).

Mark Dion's work came to the fore in the 1990s to establish a trans-disciplinary art practice, specifically through his engagement with the fields of science and the museum, which offered an alternative approach to traditional taxonomy.

> I think it is a marvelously challenging model today in our time of extraordinary specialisation, in which it can be impossible for people to have conversations across disciplines. Fields of knowledge have become extraordinarily specific and focused. I am a big fan of those who act as ambassadors from complex fields to a broader public: the Oliver Sacks, Steven Jay Goulds and Sylvia Earles of the world (Dion, 2013, personal communication).

This statement emphasises the value of the (precarious) freedom of the artist, which allows a reflection and overview of many other disciplines (which themselves are too narrow and well defined to allow for this). The work of both Dion[45] and Borland reflects the ongoing culture of institutional critique[46] that since the late 1960s and early 1970s has encouraged artists to develop interrogative and cross-disciplinary practices, on which this research builds (see page 159).

<u>The educational turn and contemporary art practice</u>

The 'educational turn', a term coined by Mike Wilson and Paul O'Neill (2010) is outlined through examples of artists and curators who consider artwork as an educational medium. In the text *Curating and the Educational Turn* (2010), they propose that curating and artistic production have undergone an 'educational turn'. Along with a series of invited authors, they recognise a shift in the use of pedagogical models such as talks, symposia, workshops, which were historically used to support art practice, as now being understood as the artistic and curatorial practice itself[47]. To enquire into these new developments in practice, Wilson and O'Neil organised a series of seminars and public discussions including 'You talkin' to me? why is art turning to education' at the ICA in (14th July 2008, London). Liam Gillick, who was involved in this symposium, later

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45 At the heart of this artistic research project is observation, a skill at the root of research in natural sciences and which plays an important role in the work of Mark Dion's work, as he described 'I learn from what I see. What I see assists me in what I make. My life is comprised of furtive encounters with objects and experiences which surround me, from my home to the back rooms and exhibit halls of museums, to the far flung cities I haunt, landscapes as diverse as the arctic and the amazon, to places as pedestrian as the supermarket. These experiences comprise a kind of image library in my head which assists me by honing an almost instinctive sense of knowing the emotive and conceptual power of things.(Dion, interview, 2013). Mark Dion, Ellie Ga (New York-based artist) and Sara Jordeno (Swedish) are among the contemporary artists whose work is tied to a kind of 'artistic fieldwork'(http://rhizome.org/editorial/2012/feb/2/artist-ethnographer/), which involves investigation through merging the apparent objectivity of scientific recording methods and anthropological research with a subjective, interpretive approach. Mark Dion contributed to Teresa Gleadowe's curatorial projects 'The Falmouth Convention' and 'The Penzance Convention' which explored the concept of artistic fieldwork through a series of site-specific events in the Cornish landscape.

46 See Andrea Fraser. 'From the Critique of Institutions to an Institution of Critique', Artforum (2005)

47 A few examples of this practice can be seen in the examples of Daniel Buren and Pontus Hulten's Institut des Hautes Etudes en Arts Plastiques, 1996, the 'Platforms' of Documenta 11 in 2002; the educational leitmotif of Documenta 12 in 2007, the unrealized Mainfesta 6 experimental art school and the Paraeducation Department.

published an article based on this talk called 'The Fourth Way' in Art Monthly (Gillick, 2008) where he states: 'in exhibitions and biennales in recent years there has been a move towards including quasi-educational projects – not as add-ons but as an integral part of artistic production'.

This research shares many characteristics of practice situated within the 'educational turn', combining strong educational motivations and an interest in sharing artistic process rather than product. It contributes through presenting and discussing methods that develop a way of seeing and understanding the morphology of animal, vegetable and mineral in the context of collaborative interdisciplinary workshops that are led through an open dialogue between participants, myself and the collaborating scientist.

The questions addressed in this research demonstrate its strong epistemological motivation[48], which is supported through the dissemination of the drawing methods developed through the Cornwall Morphology and Drawing Centre (CMADC). CMADC is a drawing research space that presents the process and product of this research through collaborative workshops and aims to share the epistemological value of drawing in relation to the natural sciences and mathematics, as discussed in detail in the last chapter of this thesis.

How to read this thesis

While reflecting on the nature of this PhD research, especially the thesis, I have found James Elkins' classification of the different kinds of practice-based theses to be helpful (Elkins, 2009:145). I situate this thesis close to what he describes as 'philosophy or art theory', as opposed to an art historical, art criticism or 'thesis as art' approach. Under Elkins' framework this thesis can then be understood as a philosophical and practical investigation into drawing as epistemology for morphology, through which I have collected idiosyncratic elements from many disciplines; mining both theory and practice for material that can be used in this research and further extracting from this material through drawing.

This thesis reflects the way that I have sampled and absorbed theory from other domains and selected key ideas based on my experience and knowledge in parallel with the development of practice. Through the lens of my own practice this 'sampling' enables the adaptation of key ideas from other domains to 'feed' into my artistic practice. As

48 Education is the preferred term over pedagogy here as it does not privilege teaching over learning.

such, theory informs practice and vice versa. An important aspect of the practice is a strong motivation to share the new knowledge that is created, through transferable methods as a continuous process of open-ended knowledge formation. This is similar to what Holert describes as 'a constant flow back and forth between the fundamental and the applied, between the theoretical and the practical [...] by a shift away from the search for fundamental principles towards modes of enquiry oriented towards contextualized results' (Holert, 2010: 322). The resulting artworks, exhibitions and workshops accompany this thesis as a digital archive and analogue exhibition.

The chapters of this thesis provide a theoretical and contextual framework for practice, containing details of the literature and artwork consulted in the course of the research and are best understood as a series of sequential episodes faithful to the path that this practice-based research took. Each chapter reflects a distinctive aspect of the process at a particular time, and each leads forward to the next iteration of practice and investigation. The first chapter gives an overview of the methodological approach to the research questions, which evolve through practice. The second chapter comprises two articles about drawing in the context of natural science and mathematics (both published in the journal *Leonardo* and following a format that is distinct from the style of this thesis). The first of these is 'Endangered: A study of the declining practice of morphological drawing in zoological taxonomy' through examples of current morphological practice at the NHM. The second article, 'On Drawing and Mathematics', specifically explores drawing as a research and collaborative tool in scientific and artistic research. Together, these articles explore drawing as a way of knowing in contemporary zoological and mathematical science. 'On Drawing and Mathematics' is co-authored, but is an article driven by this research, as recognised within the text.

These initial chapters provide examples of drawing as a way of knowing morphology, in collaboration with contemporary natural scientists and mathematicians, which then combine to create a narrative for the development of drawing as a way of knowing in my own artistic practice. Chapter three introduces the importance of resemblance in my drawing practice and reveals how the study of the morphological resemblances between animal, mineral and vegetable species in museum collections led to the emergence of the concept and practice of Isomorphology, and to an alternative approach to classification through drawing. Isomorphology is then introduced as a theoretical and practical study of the forms and symmetries of animal, mineral and vegetable species through museum specimens (3-D objects), but can also contribute as an application in scientific fieldwork, for example in Colin French's 'ERICA' plant identification software (see page 135). Building on Isomorphology, chapter five explores Goethe's original concept of morphology and adapts Goethe's morphological approach to create a drawing method. This chapter redirects Isomorphology from the study of form and symmetry in whole organisms, towards parts of organisms and, at the same time, initiates a move from observation to abstraction. Following this, chapter six explores relationships between Goethe's morphology and selected works by Paul Klee, through which I propose that the artist can be a morphologist. Klee's work reveals insight into the dynamic nature of form, arriving at similar morphological insights to Goethe. This chapter provides a basis for my own exploration of form as a dynamic and time-based process and is followed by the short chapter 'Notes from an artistic collaboration', which documents an experimental collaboration with the mathematician Alessio Corti, based on the question: 'Is it possible to draw a tree in the fourth spatial dimension?'. This chapter uses analogy and metaphor to enable a shift from an observational to a conceptual understanding of form. The next chapter explores the influence of Paul Klee, D'Arcy Wentworth Thompson, William Latham and the conceptual science of Theoretical Morphology on the development of 'Isomorphogenesis', a drawing-based algorithm informed by biological principles. The final chapter on the Cornwall Morphology and Drawing Centre (CMADC) is a culmination of the practices and collaborations described throughout this thesis, and documents how these practices are shared through a series of participatory workshops with artists, natural scientists, students and the general public. The conclusion then summarises how this thesis has addressed the research questions and points toward the potential for the continuation and development of its subject through further research.

This PhD submission comprises multiple connected elements. The collected practice and research of Isomorphology, Isomorphogenesis and the Cornwall Morphology and Drawing Centre (CMADC) have generated outcomes in the form of artworks, exhibitions and workshops. These activities are documented throughout this thesis, which is also supported by additional material in the appendices.

Identifying the limitations of the research

As described above, this research largely took place at the Natural History Museum and encountered a number of limitations. As an independent researcher, I did not have access to the NHM specimen database 'Data Portal' (http://data.nhm.ac.uk) or to

contemporary imaging technologies at the NHM Imaging Analysis Centre[49] due to the entailed expense of training and bench fees to work with such equipment.
Aside from these procedural limitations, I encountered further limitations due to the varying availability of individual scientists, and their level of interest in my research project. Disciplinary differences emerged in debates around the nature and status of what different scientists considered as "the scientific method" – a notion I discovered to be still quite ingrained in some (though not all) of my collaborators. Earning credibility with scientists who had not previously given time to engage with an artistic research project was challenging. The large number of scientists who contributed at varying stages of this research provides testimony to the success of this project.

In addition to the limitations of this research, it is important to acknowledge the difficulties when undertaking research with a broad constituency of participants (from scientists to artists and workshop attendees). A difficulty due to disciplinary boundaries appeared during the workshop practice. Inviting scientists to engage with an experimental (and rigorous) drawing method was challenging. Certain scientists held different and often heterogeneous views of the scientific method which prevented an openness to some of the proposed workshop activities. At the other end of the spectrum, structuring workshops with a rigorous and systematic (quasi-scientific) programme proved challenging for non-scientists. These constraints were predictable and did not, in my view, undercut the validity of the research. In fact, they reinforced the very aim of this research as a pluralist epistemology for morphology intended to bridge the gaps between the differing views and approaches of art and science and to show their relative merits especially when placed in dialogue with each other.

In this thesis, certain data, for example the workshop feedback, are used as corroborating evidence rather than as a subject of analysis. As a consequence, data from the workshops have the status of what I hope is informed reflection rather than thorough-ongoing interpretative analysis. The workshops had a double function: to be successful as a workshop for participants and to be successful as an integrated component of the enquiry. As a consequence of this double function, I encountered the difficulty of acquiring sufficiently detailed and consistent feedback (largely due to the voluntary nature of the feedback request – although almost everyone contributed

49 Including scanning electron microscopes, a confocal microscope, a transmission electron microscope and state-of-the-art computed tomography scanners.

largely positive responses) to assess the specific learning outcomes of participants. I did not take the feedback as quantitative evidence, but as a qualitative component of the evaluation which I could collate into more general corroborations of how I met the research objectives (see page 309,318 and 320).

Chapter Two

Methodology

My research questions focus on drawing as epistemology for morphology and require engagement with scientific collections and specimens. I have been working with museum specimens since 2006, mainly studying the resemblance between animal, mineral and vegetable species through the collections of The Natural History Museum, Kew Gardens and University College London. This research practice is based on a hypothesis that a group of underlying morphological characteristics (forms and symmetries) are shared by animal, mineral and vegetable species. This hypothesis was based on an intuition developed through my own empirical and conceptual approach that is supported by an interpretation of Goethe's Morphological framework (see page 151). This methodology articulates drawing as a research method in tandem with other methods, which are outlined in the different sub-sections of this chapter.

I have constructed a mixed methods approach (Gray and Malins, 2004) to describe morphological relationships between phenomena in the natural world. Although this work is nested in the emerging field of 'drawing research' it is distinctive in its proposal of observational and conceptual drawing practice as epistemology for morphology, as inspired by Goethe's morphology. Thus, the recursive nature of this research relates to what Daniel Zeller identifies as a goal of artistic research 'to discover a new vocabulary and new rules that can be incorporated back into the process, like a feedback loop, allowing the cycle to expand and evolve' (Zeller, 2011).

Artistic research generally, and drawing in particular, is now recognised as a form of interrogation (Holert, 2011). In this research, I employ drawing as a method to interrogate the forms, symmetries and formations of animal, mineral and vegetable structures and to offer 'artistic visualization as critique' (Ambrosio, 2014:134-137). Building on this initial framework, more specific details of how these methods have been developed and then shared with others are outlined in each of the following chapters.

<u>Positioning this practice-based research</u>

I identify my research with the term 'Artistic Research', as defined in the KZT special issue 'Artistic Research': discursive practice constituted by the interplay between conceptual thinking, a physical engagement with processes, things, objects, materialities and institutions' (Holert, 2011). This PhD presents Artistic Research into, through and for arts practice (Frayling, 1993: 5). In this context, artistic practice occupies both the research process and the research outcome. This is what makes 'artistic research' distinctive from research in other academic disciplines engaging with the same issues (Borgdorff, 2010: 57).

There has been a great deal published on the debate around art-practice-led research in the last decade. Gray and other authors[1] debate how an arts-based methodology is often constructed by the research rather than selected at the beginning. The complexity of this research has not allowed for simply choosing an empirical or qualitative methodology at the beginning and sticking to that approach: rather, the methods described in this methodology evolve throughout this research. These methods are open to unpredictable results and allow for a dynamic process of enquiry. Gray describes 'a characteristic of "artistic" methodology as a pluralist approach and use of a multi-method technique, tailored to the individual project' (Gray, 1996: 15). Thus, this methodology follows Gray's characterisation of artistic methodology as pluralist in approach.

The evolving artistic research culture has provided artists with 'the capacity to explore and explain complex theoretical issues that can have significance across broad areas of knowledge' (Sullivan, 2010: 42). Following this, I have drawn from my interaction with other disciplines as a key element to inform my own drawing practice and the written elements of the work. This research is therefore tailored to the conditions of working in collaboration with scientists and museum collections. The methods of observation, drawing, microscopy, fieldwork and collaboration employed in this research converge to varying degrees with those of empirical and conceptual science; but the questions, motivations and outcomes are different. The questions of this research have emerged from drawing practice and can in turn be addressed through drawing practice. This research can therefore be understood as complementary to the traditional approaches of the sciences because it works from a different set of questions to produce a different set of answers through a process which is open to unpredictable results (and is therefore also comparable to science).

1 See for example: Barrett and Bolt (2007), Gray and Malins (2004), MacLeod, Beardon, and Holdridge, (2005), Clough and Nutbrown (2012)

Artistic research is a relatively new field. As propounded by Borgdorff (2010), the research method is the artistic practice. Approaches, questions, answers and research arguments evolve through the practice. There have been many attempts to frame research approaches to the arts (Frayling, 1993; Strand, 1998; Sullivan, 2010; McNiff, 2013) which have largely considered artistic research as qualitative, generalised by Frayling as an approach which 'does not, typically, begin with a predetermined set of questions or assumptions but arises from the particular situations and context' (Frayling, 1993: 22). Categories of art research methods are often denoted through hyphenated phrases, such as practice-led research, practice-based research or practice-orientated research (Dallow, 2003: 51). Frayling's earlier examination of the role of art and design in relation to research practices in 1993 led to the identification of a typology of artistic research depending on the focus and approach referred to as: research into arts practice, research through arts practice and research for arts practice[2] (Frayling, 1993). My research cannot be classified discretely into any one of these types of research, rather, it creates a hybrid approach that begins with research into drawing as a scientific and artistic practice, then continues as research through drawing building towards the generation of new methods, supported by research for drawing through the presentation of findings and evidence of results of individual and collective practice (exhibitions and workshops).

During the research process there has been a continuous examination and exploration of how the research is practised and developed. This has led to the kind of reflexivity advocated by Haseman and Mafe as occurring 'when a creative practitioner acts upon the requisite research material to generate new material which immediately acts back upon the practitioner who in turn is stimulated to make a subsequent response' (2009: 219). While offering insight into how reflection and action have developed in synchronicity, this chapter provides a rationale for the selection of chosen research methods and highlights conceptual issues and research questions that form the context surrounding each of the chapters of this thesis.

A short note on objectivity

At this point, let me elaborate an argument on the concept of objectivity, which will assist the understanding of the nature of this artistic research within a scientific

2 These types can be distinguished generally as: research into art practice (includes the history, theory and criticism, as well as the social cultural viewpoints), research through art practice (the production of work and its documentation), research for arts practice (includes the performative processes, looking towards new fields of practice, and where the end product is most likely an artifact) (Frayling 1993: 5)

context. The purpose here is not to critique science or to diminish its aspirations, but to encourage a thoughtful understanding of its nature and to make the links between scientific research and artistic research clearer: artistic research cannot be purely subjective just as scientific research cannot be purely objective, rather, both have elements of subjectivity and objectivity at the same time.

If we look back a few centuries, the Enlightenment programme depended on the disenchantment of nature (Ravetz, 1990: 105), but it did not depend on objectivity, at least not as we conceive the term today. Daston and Galison propose that objectivity was introduced around 1830[3] as a conceptual framework for looking, seeing, and representating that lasted until the middle of the twentieth century (Daston and Galison, 2010: 371). Daston and Galison highlight the term 'mechanical and structural objectivity' as just one in a series of philosophical positions adopted by science in its history, taken up in the early nineteenth century as a successor to the previous 'truth-to-nature' position of the Romantic period. They then establish that rather than objectivity being an enduring foundational framework within which scientists have always operated, it actually only lasted for around one hundred years before being replaced in the mid-twentieth century by the idea of the 'trained judgment[4]' of skilled experts who have undergone an educational and practical training programme appropriate to their chosen field (Daston and Galison, 2010: 309-363). However, mechanical and structural objectivity still exert a powerful influence on what contemporary scientists and the general public understand to be 'modernity'. Brett Wilson[5] refers to Daston and Galison (2010: 260-261) when he describes the sustained attachment to the concept of objectivity, saying:

> The frequently-repeated sentiments of contemporary scientists that their theories and experimental work are all based on some form of 'objective reality' that can be independently accessed by carefully structured experiments and the removal of personal bias is a position that effectively conflates two separate philosophical stances: that of structural objectivity, as outlined above, coupled to scientific realism, which claims that scientific theories are not just useful, but true in some sort of absolute sense (Wilson, 2014: 15).

3 Daston and Galison's claim about the 'birth' of objectivity remains controversial among historians of science.
4 This idea of 'trained judgment' can be applied to the drawing practice as outlined in this artistic research.
5 Wilson was formerly a scientist (physics and engineering) and is now visiting senior research fellow at the University of the West of England, acting as 'Scientist in Residence' in their art department.

He goes on to discuss how post-modernists view theory-making as reflecting a form of socially-constructed consensus across the scientific community and focuses on asking how such a consensus comes about and how it is maintained by the challenges of others. Wilson concludes in saying that any claims of knowledge on the basis of 'uniquely mediated access to any form of external objective knowledge will always come under challenge by one group or another' (Wilson, 2014: 16). He then describes what he considers as a promising approach of 'embodied scientific realism', as described by Lakoff in Philosophy of the Flesh (1999), where any subject-object dichotomy and mind-body dualism is avoided by accepting that we are inextricably coupled to the world through our embodied concepts derived from the nature of our sensorimotor abilities and experiences (Wilson, 2014:16).

Science now seems to be abandoning the idea of an absolute and unchanging truth as implied by disembodied scientific realism, and relies instead on a more flexible narrative based on internal consistency, testability and falsifiability. As Sian Ede observes, 'in practice, scientists operate in a culture not of explicit certainties, but of doubt and question, less with the aim of securing absolute truth and more with pursuing the theories which best explain the phenomenon under examination' (2000: 38). This kind of open-ended fact-making relates to Claire Waterton's participatory experiments which look at the way indeterminacy is an integral part of science and politics[6].

<u>Research questions</u>

The following questions have directed this research. They have emerged from drawing practice and are in turn addressed with drawing as a primary method of investigation. The research process follows the demands of these questions through a multi-faceted, continually evolving methodology.

The first question is about the artist's active role in society: it is about drawing as a way of knowing and about knowing about drawing as a way of knowing.

1. What contribution can an artist make - especially through drawing effected in collaboration with scientific practices and instrumentation representationally,

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6 Waterton conducted a participatory experiment at Loweswater in Cumbria (details of which can be found in the chapter an 'Experiment with Intensities: village hall reconfigurings of the world within a new participatory collective' (Claire Waterton and Judith Tsouvalis, 2015). Waterton has also looked at the way indeterminacy is part of interesting science and politics in the article 'Indeterminate bodies for environmental politics' from Body and Society (2015). (relates to Stengers argument in 'Deleuze and Guattari's last enigmatic message', (2005:151-167)

> analytically, and in terms of interpretation - to achieving a new understanding of morphology (animal, mineral, vegetable) for both artists and scientists?

Based on my experience of working within a scientific context (both in the museum and the field) this question will first be addressed in Chapter Three through specific examples of drawing practice in science. Through two distinctive studies (one zoological, one mathematical) I explore the epistemological currency of drawing from both an artistic and scientific perspective. In the later chapters this question is addressed through the development of new methods that combine aspects of art and science practices which I identify as contributing to morphological knowledge. These methods are then practiced and tested through the dissemination of artworks and the delivery of drawing workshops, which are the focus of reflections that are embedded throughout individual chapters[7].

The second question is about drawing as an epistemological mode of representation and identifies what this artistic research aims to reveal:

> 2. What shared morphological characteristics (form and symmetry) of animal, mineral and vegetable species can be identified, known and represented through the process and object of drawing? And how can this research develop an extra-scientific model of classification which is complementary to the scientific approach?

To address this question I worked with the Natural History Museum, to observe and handle specimens and to bring this question into a dialogue with scientists. An important aspect of this engagement has been the communication of my ideas to the scientific community at the NHM in order to identify scientists who may be working with morphological questions and to generate discussion. This has been achieved through the arrangement of meetings with zoologists, botanists and mineralogists and through the delivery of public and internal events at the NHM[8]. This involvement with the NHM allowed for sustained observation of scientific practice, which has been important to gain insight into the scientific characterisation of the domain of morphology and the methodology appropriate to this domain.

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7 The exploration of drawing as epistemology for morphology is philosophical in approach, while drawing workshops provide qualitative feedback about drawing as a way of knowing, that is iteratively built into the later stages of this research.

8 NHM: Nature Live Public Event (2013), Science Uncovered Public Event (2013) and an internal Life Sciences seminar (2013).

This second research question seeks to establish the shared forms and symmetries of animal, mineral and vegetable species - not as infinite, but as a flexible set, small enough to be useful as a navigational tool within the scientific museum and the field. In applying this question, scientific objects in the museum also become artistic objects. This question then raises an ontological issue through opening up new objects of investigation for both art and science. In 'What Can Be a Scientific Object? Reflections on Monsters and Meteors' (1998: 35-50) Daston asks 'what can be a scientific object and why?' and explores the ontological, epistemological, methodological, functional and aesthetic features which qualify some and disqualify others as valid scientific objects[9]. This research re-purposes and re-positions objects which are currently considered scientific, by asking new questions and by offering drawing as epistemology for morphology.

<u>Research methods</u>

In what follows I open a discussion of drawing, touching upon various subjects: drawing and decision-making, observational drawing, drawing and memory, drawing and the tacit, drawing and the haptic. After this, all methods are discussed in relation to drawing practice through a selection of topics[10]. Each method can therefore be understood as into, through or for drawing. This discussion aims to build a rationale for drawing as a research method itself and one that also connects the other methods outlined.

Towards the work on these subjects, I have continuously surveyed the literature to inform this investigation at every stage. Reading is carried out in the service of each of these methods; motivated by the search for understanding and for ideas and analogies that can enhance the drawing process and which can be tested through practice. As this research is largely based in museums, it also draws from archival material and objects. The literature search is often prompted by the objects and collections explored through this practice, which involves reading around the objects using archival material available in the museum and in university libraries. Reading material is often recommended by supervisors and collaborating scientists, who often advise on scientific papers to read in order to advance the conversation. The reading process also generates its own questions that can often be re-addressed in part through further reading.

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9 Along with the quest for 'regularities' in nature, Daston identifies criteria such as observability, cultural significance and beauty, while also emphasising how these contribute to the sense of 'wonder' that informs scientific study. Daston describes qualities other than regularity which can be attributed to scientific objects and these include: beautiful, observable, culturally significant or universal while also emphasising the role of wonder in scientific study.

10 Including; etching and watercolour, interdisciplinary collaboration, microscopy, field-work and workshop practices.

This matrix provides an overview of the research methods, which are discussed in detail in the following sections.

Research topic / Method	Epistemological value of drawing (chapters: 3, 4, 6,7,8,9)	Morphological understanding and classification (chapters: 4, 8)	Historical and contemporary understanding of research (chapters: 1,5, 6, 8)	Artists' contribution to morphological understanding (chapters: 3, 4, 5, 6, 8, 9)
Research into drawing practice	Collaboration with scientists Conversations with scientists	Artist in residence within scientific institution practice Shadowing scientific fieldwork Conversations with scientists	Visiting exhibitions	Workshop design, administration and delivery; Exhibition making Reflection on drawing practice Collection of feedback from workshop participants Contributing to conferences in art/science fields Publication of research in academic and non-academic contexts
Research through drawing practice	Observational drawing practice Observation of scientific practice Collaboration with scientists	Microscopy Haptic engagement with museum collections	Drawing from historical and contemporary artworks	Drawing, etching and watercolour
Research for drawing practice	Collaborative drawing Skype and email exchanges with artists and scientists Reflection on drawing practice	Compiling unique list/database of specimens with shared morphological features Visiting museum collections Handling museum collections; Negotiating access to collections Organizing and managing a series of meetings with scientists and curators at a number of institutions	Researching in archives library research Literature review in art and science contexts	Attending workshops of other artists

Drawing

As a method that can generate and communicate knowledge across disciplines, drawing is employed throughout this research to investigate, synthesize and communicate the shared forms and symmetries of animal, mineral and vegetable species.

Drawing is the foundation from which the other methods have grown. The process of drawing can 'make visible' (Klee, 1973: 21) relations between things that otherwise remain invisible. This research proposes drawing, specifically line drawing, as a way of knowing. This is supported by continuous reflections on drawing practice through keeping a journal, extracts of which are reported in relevant places in this thesis. The journal contains reflections that emerged from the practice itself as well as from activities that informed it in less obvious, but equally relevant ways. Part of the observational aspects of the practice, for example, were carried out and elaborated upon through the simple act of walking – as a way of connecting with the landscape where the comparison of morphologies can also unfold. As an embodied, volitional activity, drawing, like walking, involves more than can be expressed in language. The later section 'Drawing and the Tacit' aims to capture the explicit aspects of this connection and to account for aspects of the practice that resist systematic description.

Drawing and decision-making

When reflecting on the personal and experience-led drawing process, in which the subject and the object are constantly being negotiated, I am reminded of Nietzsche's statement: 'There are no facts, only interpretations' (Nietzsche, 2011, 89). Scientific work often aims to neutralise any subjective mediation involved in interpretation, whereas in this research the subjectivity of drawing enables the selection of what is interpreted whilst remaining connected to the observation of 'objective' morphological characteristics. Drawing creates a communicable common ground where these morphological characteristics can be negotiated and re-positioned, and this is a useful exercise for art as well as science. In this way, drawing offers a particular form of objectivity: one that allows for the priorities of the individual. The lived character of drawing experience requires a first-person perspective on the object of study. Also the interplay between subjective and objective work is central to this practice, which will sometimes be described from a first person perspective.

In *Objectivity* Daston and Galison identify concrete practices of abstract reason by Enlightenment naturalists as: 'selecting, comparing, judging, generalizing' (2010: 70). Drawing involves continuous selective decision-making over time, and feedback between the drawer and the drawn. As the driver of the drawing, the human is both the technology and the mediator. Drawing – as mediation – is different to a photograph or digital image because there is no (non-biological) mechanism between the drawer and drawn. Drawing requires the drawer to select salient information (Anderson, 2014a), which varies depending on individual experience. The drawing process also involves feedback: as dynamic sensory transference from the optic to the kinaesthetic to the haptic which requires concentration and interactive decision-making.

In this sense, drawing is comparable to the selective process of note taking described in Field Notes on Science and Nature (Canfield, 2011), as rather than transcribing the whole subject, a selection of salient information is transcribed. The active selection process of drawing determines what is of interest as a form of analogue data processing that functions to process information through the act of making. A key aspect of the 'skill' of drawing is developing confidence through which decision-making becomes less conscious and flows without interruption. The line has agency in this decision-making, as subjects must be delineated and lines must be selected. The drawer must decide which lines are essential to the description and which are unnecessary. The ability to make these decisions is enabled by understanding that a position of not knowing can positively help to generate curiosity and questions that form the basis of work.

Observational drawing

Goethe describes how 'every act of looking leads to observation, observation to reflection, reflection to combination, in every attentive look on nature we already theorize' (Goethe in Seamon, 1998: 57). Concentrated observation within the act of drawing creates new perceptual knowledge. Morphological information can be observed in detail, thus activating the process of comparison; each form observed stimulates a new understanding and joins a 'bank' of knowledge in the observer's mind. Each new drawing experience then triggers a different formal memory 'stored' in this 'bank', which is evident in the visual relations of the Isomorphology series (see page 95).

'It is not the data that change in a gestalt switch, rather it is we who change.' (Seamon, 1998: 32). Drawing is an embodied, lived experience, through which there is potential for transformation. The iterative nature of observation can also be understood in relation to drawing as describing:

> A mind which never receives a perception without comparing with a perception; who seeks out what diverse objects have in common and what distinguishes them from one another, who go from observations upon observations to just consequences and who find only natural analogies (Genie, cited by Daston, 2007: 58).

Analogies emerge through the act of drawing, allowing resemblance to be discovered rather than invented. Observational drawing therefore allows for the comparison of what is already known and what is observed, and for extending this comparison until what is known, what is drawn and what is observed are relatively consistent, a process which can take years of practice to establish.

The practice of observational drawing, its immediacy, simplicity, open-endedness and spontaneity, enables a heightened awareness of the morphological characteristics in nature. This awareness leads to an ability to quickly recognise morphological characteristics shared across species, which is crucial to the process of working with vast museum collections and busy museum curators to find specimens. Drawing morphological characteristics (of forms and symmetry) approximates to the notation of an isomorphic alphabet: a writing of form, but without the syntax of language (see page 91).

Observation consists of the zooming in and zooming out of details. Although it is possible to draw a complete specimen over time (consisting of many morphological parts composited together), the eye cannot perceive all morphological details simultaneously. This is why a drawing, as a medium which can select and represent salient features of morphological characteristics and the whole simultaneously, holds a unique epistemological value.

Therefore, any single drawing represents multiple and continuous observational acts of focusing in and out, which form a drawn image over time. The drawing then offers a view of an object that is otherwise impossible without the time endured in the patient act of drawing, and allows us to observe and compare details simultaneously. The temporal nature of drawing was highlighted by mathematician Dr. Tom Coates (Imperial College), who observed that 'human understanding is enabled through comparison' (Coates, Email exchange, 2014). His view supports an argument for drawing as a comparative tool, which allows morphology to be experienced as something before and something after: the process of drawing enables morphological comparison and the object of drawing can be compared with other drawings. Goethe also emphasised the importance of comparison through seriality in his quest for the 'pure phenomenon', describing how the essence or 'type' could be found through a sequence of observations and not in an isolated instance: 'to depict it, the human mind must fix the empirically variable, exclude the accidental, eliminate the impure, unravel the tangled, discover the unknown' (Goethe, 1988: 25).

Drawing from life is always an experiment because the individual nature of the specimen can be very unpredictable. The individual variations of specimens bring challenges and surprises to the work, and also to any process of classification (true of both scientific taxonomy and this artistic research). What occurs is an improvised response motivated by ideas and observations, which are reified through engaging with the real. One morphological character can be compared to another and through drawing body parts can merge, transplant and exchange as form takes precedence over scale. In this improvisation morphology suggests art, and the lengthy and patient observations are rewarded through a joyful and creative experiment in drawing, each with its own individual modifications. Goethe insisted that this combination of insight and synthetic judgment required the observer to detect 'the idea in the observation' (Goethe in Daston and Galison, 2010: 233) which approximates to what I have just described. Building on this idea of 'the idea in the observation', Daston and Galison consider that the qualifications necessary to see like a naturalist include synthesis, adding that 'to see like a naturalist required more than just sharp senses: a capacious memory, the ability to analyse and synthesize impressions, as well as the patience and talent to extract the typical from the storehouse of natural particulars' (Daston and Galison, 2010: 58). These qualities clearly relate to the process that has been described here. In the space of the page, the physical distance between museum specimens, normally housed in different parts of the museum, is confounded and allows for 'extra-scientific' comparisons revealing general patterns and processes at different scales and in different orders of being.

Observation, mediation and memory

This section offers brief interpretations on how drawing and photography entail different forms of mediation and memory.

Drawings can become powerful 'aide memoires' as the result of drawn experience which accumulates as a kind of memory bank of perceptual experiences, which can then be recalled by further drawing experience. In this way, drawing can function as a mnemonic device, which is created and sustained by practice. This argument is explored in more detail in Chapter Four where the role of resemblance as an ordering principle and mnemonic device is explored through specific examples.

An important aspect of human memory is the visual sense - viewing a drawing post-production can transport the drawer back to the centre of the experience. Drawing is therefore a way of transforming invisible experience into visible, material and embodied knowledge, which in turn transforms further experience. Drawing exercises the mind through a process that does not cling to any object, but rather transforms through objects of study with emphasis on a creative engagement in the process. This transformation propels thought towards the next stage of investigative experience. The drawing process challenges the impulse to attach, name and possess and to make the present into the past prematurely. Drawing therefore extends the ability to experience a subject in and through real time in order to achieve a qualitative object that is the result of its own unique process of making, which cannot be obtained through a quantified exchange.

In the case of the photograph, the camera mediates – and how much agency directs the image from behind the camera is a debate that cannot be fully addressed here. Aspects of the photographic experience are externalised through mediation and therefore impact the observer's work in a different way to drawing experienc. Sontag offers an interesting reflection on these differences, 'people remember through photographs but that they remember only the photographs [...] the photographic image eclipses other forms of understanding [...] To remember is, more and more, not to recall a story but to be able to call up a picture' (2001: 94). It is the length of time spent through drawing experience that increases this ability to 'call up a picture' from the depths of our memory. There are two thoughts here: first the camera mediates in a way that doesn't happen with drawing, and second that drawing takes more time. Drawing tells a story and helps us, as Sontag emphasizes 'to call up a picture'. Viewing a drawing is a way of recalling 'a story' which activates the connection between memory and experience as opposed to recalling an instantaneous picture.

As a process requiring sustained engagement and feedback, drawing is less mechanistic than engagement through a device like a camera or a computer program, in which aspects of the process happen without human interaction. With mechanization some of the mediating process is beyond the agent's control. Photography can freeze an instance, creating a time slice of the dynamic world, drawing can open and unfold an experience through an engagement with a series of connected instances.

Through the act of drawing, time and space are contained and mediated by the drawn line. Drawing allows for an expansion of the subject through a time-based practice.[11] The following is an excerpt from my journal, reflecting on practice:

> In the duration of drawing, the past presses against the present enabling a new form to emerge. The process of observational drawing slows the tempo of my visual and embodied experience and provides a contrast to the contemporary

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11 The duration of drawing as lived experience, and as process is likely to open up in further post-doctoral work on Bergson's Creative Evolution.

> 'digital' speed, enabling a strong, time-based connection between the drawer and the drawn. These different speeds, a kind of multi-temporality, are intrinsic to the result of producing different kinds of knowledge. Drawing provides space for thought to form, for decompression and release which is essential for the creation of new ideas. (Anderson, Journal, 2014)

One way of looking at drawing is to see it as a honing of the human being as a scientific instrument, an idea which is important to the process of Goethean observation: 'For Goethe, the human being is the most powerful and exact instrument if we take the trouble to sufficiently refine our sensibilities' (Naydler, 1996: 23). In the dynamic process of drawing, then, the artist is the mediating instrument as the eye constantly moves over areas of contrast in the dynamic process of seeing. The eye navigates the object searching for lines, structures and patterns, for dark and light and for colour. Drawings not only represent the subject they describe but also the embodied human experience of the seeing process itself.

Drawing and the tacit

Michael Polanyi summarises the idea of tacit knowledge in his work *The Tacit Dimension* with the assertion that 'we can know more than we can tell' (1967: 4). By this he implies that there is knowledge that cannot be adequately articulated by verbal means, and suggests that all knowledge is rooted in some kind of tacit knowledge. Polanyi tells us that tacit knowledge can be acquired without language and this is part of the reason why it can be difficult to share and to describe. Observation and drawing combine to form tacit and language-less knowledge of the specimen[12]. Therefore drawing, like observation, is its own teacher. Polanyi also tells us that the key to acquiring tacit knowledge is experience and that without some form of shared experience it is difficult for this knowledge to be disseminated. The drawing practices generated through my research can only be shared within a relevant context. As a method for creating an appropriate context, workshops have proven an integral part of the work. The realisation of the full potential of drawing as a way of knowing requires the engagement of the drawer, or what Polanyi refers to as 'the knowing subject' (Polanyi, 1967).

An example of tacit knowledge which relates to my research, which aims to recognise and to know morphological features through drawing, is that of facial recognition

12 This differs to the current Scientific Linnaen approach which relies heavily on the practice of naming and numbering nature.

given by Lam (2000: 489), 'We know a person's face, and can recognize it among a thousand, indeed a million. Yet we usually cannot tell how we recognize a face we know, so most of this cannot be put into words'. When observing a face, or in this case a museum specimen, knowledge of the individual features is not always conscious, but it is still possible to recognise the museum specimen through recall, association or direct handling which all contribute to a tacit way of knowing (Lam, 2000)[13].

Another way that I have understood the tacit nature of drawing as a way of knowing has been through comparing drawing with walking[14]. Rather than understanding walking[15] as a medium in this research, I see walking as a practice that helps to direct the complexity of thought – often as a linear movement, a function comparable to drawing. Walking has enabled me to think about drawing as a parallel activity one dimension up: walking is drawing in three dimensions. The linear movement, forming through space is sometimes punctuated by observations and restful reflections that weave in and out of focus[16]. Walking is a dynamic way of experiencing the movement, rhythm and tempo of the body as it creates invisible lines within a landscape. As such, the trace of a walk can be compared to the trace of a drawing; a body scaling the landscape as the hand and drawing tool scale the page, or, as Klee famously put it 'taking a line for a walk[17]'(Klee, 1973).

In walking I am most frequently following a line - a path that has been defined for me and walked by countless others - whereas in drawing I create the line freely within the space of the page. My eye is following the line of the morphology I am observing, empirically and conceptually, and I am visualising, analogous to how the body is following

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13 Further literature on the tacit is given by Parsaye and Chignell, (1989), who describe three approaches to the capture of tacit knowledge which relate to this research: Interviewing experts, Learning by being told, Learning by observation.

14 The tacit nature of walking has been explored by Ingold and Vergunst, in Ways of walking: Ethnography and practice on foot. 2008.

15 Walking has emerged as a medium since the 1960s, with renewed relevance in contemporary art (Solnit, 2002), most notably in the work of Hamish Fulton, who declares "If I do not walk, I cannot make a work of art" (Fulton 2012). For Fulton, walking is at the foreground of artistic practice, as a medium, whereas walking functions as propaedeutic to my practice.

16 The drawing and walking process both involve focusing in on details and zooming out to see the whole picture simultaneously. This play between the micro and the macro creates a sense of connection and location to the body that is being travelled; an object or a landscape, embodied within and without. In travelling with and through the line, we arrive somewhere unique, which constitutes the individual nature of our own experience: drawing or walking.

17 Walking can also be understood through line, as Klee famously described drawing 'to take a line for a walk' (Klee, 1973). This theme is reflected in the exhibition: 'Taking the line for a walk' exhibition with works by Olav Christopher Jenssen, Paul Klee, Jonathan Lasker, Brice Marden, Henri Michaux, Mark Tobey, Cy Twombly and Christopher Wool at the Paul Klee Zentrum, 2015.

the physical line carved in the landscape. Like drawing, walking provides a space to reflect without interruption, offering unique intellectual value in the reorganising of concepts and revitalising of ideas: expanding thought in space and time, enabling elements to move around and to recombine, to move forwards or backwards, or just to move around. Walking through a landscape becomes a way to get to know the shape of the landscape over hours and days and to feel the three-dimensional form of the landscape through the senses. Both drawing and walking are processes that enable an individual – as an agent – to know and transcribe the world as a three, even four-dimensional space[18].

Drawing brings a deep sense of embodiment and connection to our experience of the world, providing a space to hold and to unfold complexity. There are continuous changes: pausing to observe, choosing direction, changing tempo, transitioning between focused and wider attention, inside and outside the line, of selecting what to take forward and what to let go.

> As I draw and walk, I wonder what is the difference of being within and without the line? To be within is to be moving, with direction … contained … pausing, reflecting, with a sense of direction purpose and growth. To be without loses direction, focus, and linearity. The drawn and walked lines that I make are not straight, they meander in and out of near and far, of particular and whole, pausing and changing direction as the path unfolds, always in a state of becoming… experienced as the moving present. Through the line we pass from where we have been to where we are going, the drawn experience is always dynamic (Anderson, 2014, Journal extract).

<u>The haptic: working in the museum</u>

The drawing process aligns internal duration with external representation. The act of handling museum specimens reduces the physical distance between the observer and the observed. In this handling process, the duration of viewing might differ greatly, all the way from a glance to a profound meditation. The drawing process, as a lived experience, provides connection with morphological structures. The haptic is important here as there is a relationship between the physical (muscle and receptor feedback loops) and the cerebral which has a unique character in drawing: the muscular engagement with the generation of the line has an important contribution to continued practice.

18 Four-dimensional as the landscape changes through time.

In order to test my intuitions of the shared morphological characteristics of animal, mineral and vegetable species, I chose to observe directly from specimens in the museum and the field. Drawing museum specimens from life is the preferred method for the exploration of the Natural History Museum's collections, and vital to this exploration is the handling of each specimen, which activates a to-ing and fro-ing between the optic and the haptic. Handling and sensing the specimen can evoke ideas about representing form and texture through line and mark-making, for example: sharp edges can be represented through angular lines or the hand can be used as the measure of scale, noticing that spindles on a shell are a finger's distance apart.

The handling of museum specimens allows for an intimate gaze and connection to the object. The ability to rotate[19] and to choose a perspective from which to draw is crucial in order to find the angle that reveals the morphology clearly and makes it comparable to the morphology of others. The drawer must select the salient information from the subject. The decisions I make when drawing from the museum specimen are different from the decisions scientists make (as we are different kinds of instruments with different tuning), although the approach has many shared characteristics, as later discussed in the Chapter Three.

<u>Drawing, etching and watercolour</u>

One of the main characteristics of morphological drawing in both science and art is of describing form with a simple, economic line that reduces the aesthetic 'noise' of the morphology as observed in real life. This approach to drawing is not concerned with shading or gesture, but is concerned with rhythm, mark making and delineation. At an early age, I was inspired by morphological drawings in scientific textbooks and by the drawings of Leonardo da Vinci (da Vinci, 1980)[20]. I have consciously maintained an approach that is consistent and comparable with this history of scientific and artistic drawings[21] which hold epistemological value. In order to communicate to both art and science practitioners and audiences, it is important that the drawings created through this research are comparable to (but not the same as) other morphological drawings. The etched line is also consistent with the fine lines of scientific drawings.

19 For more on haptic object recognition, see Lederman and Klatzky (1987)

20 Who described form through line, a tradition which can be traced through historical and contemporary drawings of art and of science, for example: Grays Anatomy (1989).

21 But I do not practice cross-hatching and other technical inventions of scientific representation.

I interpret the line as a navigator and container for the complexity of the mass that it travels through. If we take the line as an analogy for a 'pathway' - a term often used in science more generally (think of blood cells travelling in lines, and arterial and metabolic pathways) - the line delineates and creates definition for mass. All lines are linear but this does not mean they are all straight. A drawing can be a composite of many linear lines without being itself linear or 'a' line as a whole. The line can create a pathway where there was none, follow an existing path or evolve a new pathway of thought, guiding and giving form to our experience.

After years of practice, etching has shown itself to be a medium suitable to represent the morphological characteristics of animal, mineral and vegetable species due to the fine quality of the etched line, which can both reveal and compare form. I approach etching as I would a drawing: I draw directly on to the copper plate, merging the immediacy and energy of drawing with the quality of line and material inherent in the process of etching. Drawing directly on to a prepared copper plate allows only 'one chance' at the drawing as each mark is committed to the plate. This self-constructed rule of having 'one chance' at the work focuses my observation more than working with the knowledge that I can throw a piece of paper away and start from the beginning. As such, this rule is a material parameter I have established which complements and enhances my emphasis on observation. I value copper as a material, which motivates me use it well and to sustain creative engagement with the work. When drawing on copper, it is common to begin a drawing and feel that it is going 'badly'; but because I work in a 'one chance' approach, the challenge then becomes to redeem the work. This process of redemption generally leads to a drawing which is not what I expected, neither better nor worse, but a drawing that has worked through problems of observation and representation creatively. The final etching (drawing object): an end which has satisfied my questions about the subject, and through which I have gained morphological insight.

I use watercolours to emphasise the gradual nature of form change and take direct inspiration from Paul Klee's colour gradation method, which can best be understood as a numerical ratio of changes and as a continuous contrasting to and fro movement of tone and/or colour (Klee, 1973: 340). Klee compares the intensity of colour gradation to sound, describing the movement/gradation of colour along a 'tonal scale' (mixing each colour for each gradation) and suggesting colour gradation as a signifier of gradual change over time by adding a sense of motion and transformation (see page 195).

Microscopy for and through drawing

In this research the study of form and symmetry is largely at scales observable to the human eye, but not exclusively, therefore this research is not intentionally scale-specific; but it has been restricted by limited access to technologies that make scales not visible to the human eye visible. I have endeavored to use microscopy where possible as an important method to reflect on scientific drawing practice and to inform this study from a micro-scale (as the study of shared forms and symmetries is not scale dependent). This has involved collaboration with Camborne School of Mines[22] and the NHM[23] to learn the microscopy techniques which are practised as part of this research, including camera lucida microscopy, slide preparation, light microscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The practice of working with a camera lucida microscope is discussed in detail in Chapter Three of this thesis[24].

Often when drawing through a microscope, it is difficult to immediately recognise even the general nature of what we are looking at; whereas when observing a specimen at macro-scale, the correct scientific name may not be known but it is still possible to recognise that the specimen is a mineral. This is not always the case under a microscope: it is often impossible to tell from observation if the object is animal, mineral or vegetable. It is not possible to rely on previous knowledge or assumptions as in the case of drawing a figure or a landscape. Drawing in the unknown microscopic territory helps to maintain openness to the drawing process and disables the tendency to jump ahead to a name or identification prematurely. This unfamiliarity forces the creation of new questions and in return, new knowledge (for example, I discovered the triangular and spiral morphology of nematodes through microscopic observations. See page 58). Once the microscopic subject has been removed from its natural context, its abstracted state is then more conducive to methods of abstraction through the drawing process.

A difficulty often encountered when drawing from the microscope is the 'interruption' in the drawing process, i.e.: having to look through the lens and then look away towards the page and then to find the previous location within the subject. A slide is a two-dimensional cross-section, literally a 'slice' that does not have depth. This makes the experience of drawing from a slide and a photograph very different. Even though a

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22 Scanning Electron Microscopy (SEM) Training 2011

23 Camera Lucida microscope training 2011

24 This research has encountered some limitations due to limited resources and although I successfully completed training with the SEM at CSM, I had hoped to work with the imaging department at the NHM, who agreed in principle, but budgeting issues made this impossible.

photograph is two-dimensional and therefore lacks physical depth, the image often presents an illusion of depth. There is no illusion of depth in the microscopic slide, which leads to the feeling of a more surface-based engagement with pattern[25]. With a microscopic view, it is possible to get lost in the specimen as the familiar 'anchors' like the head of a figure or the hill in a landscape are no longer available. The microscopic slide is a cross-section existing within a two-dimensional plane, an alien environment that can be entered through drawing. The identification of pattern helps when drawing with the microscope, as the pattern provides structure for drawing from which we can refer back to the specimen for the particular details. Recognising a morphological pattern, for example the repetition of a branching or spherical form, is helpful but can also limit understanding, as there can be an inclination to cling to the pattern – to rely or rest on it – which can make the observation less active. To counter this, it is preferable to draw as continually informed by the particulars of the specimens, considering each as a variation on the type of pattern that is recognised.

Drawing workshops

Workshops are central to the evaluation of the epistemological value of drawing. I have considered the drawing practices developed in this research to be valuable if they prove transferable between my own practice and an art, science or general audience. Each workshop is developed through and for testing this transferability, incrementally building as insights from participants lead to new questions and new possibilities for the practice[26]. A full discussion of workshop and exhibition practice, including insight into how different people draw and observe can be found in the later chapters.

In the workshop, it is important to consider the epistemological value of drawing as both process and object. A particular kind of understanding is facilitated within the drawing process which itself aims to communicate and to be understood. The drawing methods discussed here use the line as a way to reconstitute natural objects following the history of this delineating method in natural history, science and art (Anderson, 2014). My approach to drawing connects my own work, the work of other artists and the work of workshop participants (including, artists, scientists and the general public) into a dialogue[27]. The active viewing of the drawn objects of others during the workshop

25 This is different when comparing a microscopic view of petri-dishes and slides which allow for various focal ranges.

26 Dissemination of process has also been through conference presentations and publications during the research process (which were previously outlined in the introduction).

27 Alongside initiating dialogues with scientists, I also initiate dialogues with contemporary artist William Latham

continues the cultural life of this linear kind of drawing. In the workshop, both the process and object of drawing reveal what is understood through drawing and continue to share this understanding with others. For this reason, workshops and exhibitions have been an important mode of analysis and a way of testing what and how both the process and object of drawing communicate. Workshops are not only about the morphological topic (botanical, mineral, zoological) but also about drawing and its epistemological value (see page 298).

Drawing from exhibitions and archives

In order to understand how my own drawings can offer understanding of the natural world, it is important to assess the kind of knowledge gained from the drawings of others. Visiting exhibitions and archives to observe and draw artworks is essential to understand the epistemological value of the drawings of others. This close observation of drawings as artefacts involves exploring how both the process and the object of drawing can create knowledge and meaning for others. Moreover, the handling of other artists' drawings in the archive allows for an intimate gaze and encounter with the physical drawing.

Learning from other artists' drawings is an important source of insight for this research. This aspect of the research is outlined in Chapter Six in which I re-draw aspects of Klee's experience and gain insight into the kinds of questions that Klee explored in his drawings. It is important to note that this engagement creates a form of indirect dialogue between my work and Klee's work. I also engage in a dialogue with the contemporary artist William Latham through conversations, meetings, exhibitions and workshops. The insight and influence gained from this method is discussed further in Chapter Eight.

Working with the Natural History Museum (NHM)

The collaborative element of this research is multi-faceted in nature: both formal and informal, involving meetings, working with scientific collections, conversations and drawing. Collaboration is essential to access specimens and to discuss the research questions with museum curators and scientists who know about the morphology of their collections. Direct engagement with scientists provides a first-hand account of

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through conversations, collaboration, exhibitions workshops. It is also important to note that I am in a dialogue with Klee, although a less direct kind of dialogue. The insight and influence gained from this method is discussed in Chapter Nine: 'Isomorphogenesis.'

scientific practice, which allows the opportunity to observe and to compare scientific and artistic approaches; while researching within the museum provides a space to test drawing as a mode of knowing in a scientific context.

Through my own experience, I have found many contemporary scientists still aim to be 'purely' objective, but also many admit that an element of subjectivity is bound to enter their work. Greg Edgecombe, Zoologist at the Natural History Museum London describes morphological drawing as 'unapologetically subjective, you are steering the reader towards features considered important' (Edgecombe in Anderson, 2014a: 235). This subjectivity runs through all scientific drawings, which are selective, based on human judgment and often involve altering the specimen through the drawing process, intending to change the meaning and to direct the interpretation. Like scientific drawings, the drawings of this research are selective, based on human judgment and aim to direct meaning, to communicate and to be comparable with other drawings of both science and art.

In the recent book *Art, Science and Cultural Understanding* (2014), Barbara Hawkins talks to Shelley James, artist and PhD candidate at the Royal College of Art, about her collaborative Art/Science project with Bristol Eye Hospital (Wilson, Hawkins, and Sim, 2014). James describes an 'interesting overlap' in the way she works with scientists, saying they are an 'inspiring model for sharing the craft of observation' (2014: 164). She expands on this point by saying, 'they publish papers when they are happy their work is not only repeatable by themselves, but also by others as a starting point for new discoveries – and it's cited for that very reason' (2014:164). Like James and the scientists described, I also aspire to being referred to for this reason – an aspiration that is addressed through the development of workshops which share the drawing methods of this research[28].

Despite my lack of formal scientific training, I have embedded my artistic practice within the conventions of scientific institutions and collections. This has generated a practice of asking unconventional questions and has resulted in an unconventional body of knowledge. During this process, it has been important to observe the practice of scientists at the museum in order to realise what is shared between these scientific practices and my own method, for example, observation, trained judgment and abstraction.

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28 James says 'the moment you shift from experience to articulating that experience there is always a form of translation and that's inevitably going to have some enrichment and some loss'(Wilson et al, 2014: 167)

As a morphological study, this research has grown from and required the existence of an evolving interdisciplinary network: a (fragmented) collection of natural scientists, mathematicians, philosophers and artists in London, Exeter and Cornwall. This is necessary because the natural sciences, mathematics and art overlap in their study of form, and there are many aspects that are complementary to one another. Through working with individual scientists in different disciplines, it has been possible to make links between questions of form, which emerge in different contexts, often oblivious to one another. For example, the scientists Dr.Gavin Broad (Zoologist), Peter Tandy (Mineralogist) and Professor Alessio Corti (Mathematics) were unaware of each other's work until I pointed out some similarities. Following these observations, drawing provides a way to make these connections visible.

These collaborations have been developed from meetings that came about through either independent research or leads from existing collaborators. Drawing is active as both a process and product of these collaborations and has had a twofold effect on my artistic practice: it has changed the nature of my practice and it has changed my awareness and understanding of my practice. Collaborating with natural scientists and mathematicians has affected the focus of my attention on specific scientific objects, which can be observed or reached through conceptual means to address my questions. For example, natural scientists at the NHM directed my attention towards specimens that I had not previously considered or known about, and mathematicians could answer my questions about the nature of form through collaborative drawing[29]. At first, a lack of scientific understanding seemed to be a limitation but, in time and through experience, I have grown to appreciate the 'extra-scientific' value of the questions I brought to these collaborations: These questions of drawing are different but related and often complementary to those of science.

<u>On the role of conversation in collaboration</u>

These collaborations build from a description of my general research interests and my specific interest in the work of my collaborators. Initial enquiries evolve into a conversation 'around' the specimen: its history, its individual story. It can take a long time to build the trust necessary to conduct honest and open conversations and collaborations. The conversational process generally begins with initial discussion based on the research questions, which provide the basis for dialogue and then later enters a more improvised mode. It has often been difficult to participate in scientific discussions

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29 For example, an understanding of topology and dimensionality that would be different if I were to pursue the enquiry alone.

as an artist and has required the humility to ask for further explanations. Saying this, the conversations often enter into unfamiliar territory on both sides and improvisation becomes key to find appropriate responses to transform this encounter with the unknown into a learning experience which can generate ideas and feed back into the dialogue.

Conversations range from informal exchanges to more focused conversations where I have prepared specific questions to aid the investigation and to take advantage of the evidence that emerged from chance conversations, not only with scientists that I collaborated with but also with scientists that were not collaborators and fellow artist William Latham. The conversation has been a way to source ideas and to triangulate evidence, ideas and clues I had been gathering, for the construction of the arguments that are presented in this thesis. The interview has been crucial at certain moments (for example when initiating new phases of the research) but was not a tool operationalized at the core of the artistic research projects themselves: rather, interviews supported the work and offered a way to quickly test or validate my intuitions.

Conversations with scientists have been a formal and informal part of collaborations but have also been conducted with very specific intentions[30]. Aspects of 'conversation' and 'collaboration' are key in terms of this research and also of so-called 'Relational Practices[31]'. This is a relevant contextual frame for the dialogical, collaborative and interactive approach of this research. The conversations are a lively critique within the creative collaborative process, revealing dialogue as a way of knowing which generates ideas and sometimes demands pauses in mid-conversation to make notes or draw an image that has arisen. While this process deviates in many ways from the traditional process of making an art object, it is essential to this research, which breaks away from the role of the artist in the studio[32] in order to react to and interact with science. The impact that conversations have on the drawing process, cannot be predicted, but reflect

30 For instance, when I set out to get a contemporary view of the role of drawing in morphological sciences, I approached scientists and conducted focused conversations and interviews.

31 'Relational Practices' is derived from *Relational Aesthetics* as postulated by Nicolas Bourriaud in *Relational Aesthetics,* (2002). This term encompasses a field of practices which go by a variety of names such as 'socially engaged art', 'dialogical art', 'research-based art' or 'collaborative art' (Bishop, 2005).

32 The postmodern conception of "post-studio" practice, a practice cultivated by the likes of Robert Smithson, who came to reject the confines of the physical studio as a site of production in favour of the unconfined natural landscape, or by John Baldessari's infamous "Post-Studio Art" class at CalArts, in which students were encouraged to "stop daubing away at canvases or chipping away at stone" and embrace a wider framework for art production. The influence of these artists is clearly evident in a range of contemporary artistic practices that continue to question traditional modes of production and dissemination.

the experiential specificity of the encounter. Conversations facilitate understanding, decision-making and the exchange of knowledge through a lively critique, which has become an important part of this research process.

Since 2006, I have maintained an open dialogue with a number of scientists at the Natural History Museum and Imperial College. I have posed questions that are outside the scientific remit, but which can still be considered of scientific interest, for example: 'where can hexagonal morphology be found across scientific kingdoms?'. In mineralogy it is important to know which minerals are hexagonal in order to put them into one of seven crystal systems; therefore, this question impinges directly on classification. Scientists' responses to my questions have led to many unconventional conversations and a handful of long term collaborations which explore what can be known through the merging of artistic and scientific questions and methodologies.

Drawing has played an important role in my dialogue with natural scientists and mathematicians, often acting as a shared language. An in-depth discussion of this drawing-based communication is at the centre of both articles presented in Chapter Three. Another detailed description and discussion of the role of drawing in art/science collaboration can be found in Chapter Seven.

<u>Observing scientific fieldwork and doing artistic fieldwork</u>

In order to understand the term 'artistic fieldwork', I observed and participated in scientific fieldwork with the Natural History Museum, Exeter Bioscience department, Camborne School of Mines and the Cornwall Botanical Group (Anderson, 2013). The intention was to make direct comparison between approaches, motivations and methods and to reflect on the value of 'artistic fieldwork' (Wetzler, 2012) within a scientific context. This comparison allowed for an understanding of how drawing could contribute and complement scientific approaches as epistemology for morphology in the context of the 'field.'

In order to observe and compare scientific approaches to fieldwork, I joined the NHM team of scientists on a fieldwork trip to the Isles of Scilly in 2013 and published a series of reflective reports on the experience on the NHM Nature Plus Website afterwards (Anderson, 2013a,b,c,d,e). I arranged to join this trip in order to investigate what happens when an artist joins scientists on fieldwork and takes on the characteristics of a participant, an observer and, to some extent, an ethnographer (Wetzler, 2012). This provided an opportunity to observe methods that were shared between artist and scientist, including the collection and classification of specimens, observational methods, walking and note taking. This experience enabled me to re-examine and re-imagine the concept of the field and of fieldwork and to then offer new ways to represent this experience, which relate to concepts of reflexivity and narrative as discussed in the 'new ethnography' of Goodall (2000).

The purpose and value of this (ethno-)observational method was to assess the similarities and differences between my own artistic field methods and the methods of natural scientists. In order to understand this I observed the scientific approach. During this fieldwork period it became clear that in the scientific approach there was no time for drawing; drawing was the method that I could contribute to this scientific fieldwork study.

Conclusion

As an artist, I have entered the scientific domain as an outsider, without a formal scientific education. It has therefore been necessary to create a position and to forge a space for my practice where there previously was none. The long-term collaborations I have successfully developed with the NHM and Imperial follow this goal.

Like all methods, the ones selected here have limitations: the interplay between subjectivity and objectivity in drawing, the limitation of working with a few collaborators/ scientists and the slowness of drawing, which, as I argued, can also be understood as an advantage. This methodology provides a justification of why methods have been chosen to address my research questions, while the methods are further unpacked and explored through practice in the following chapters of this thesis.

This research reveals a new perspective on the natural world as described through drawing and of the tools of this theoretical and practical framework that are suitable to detect it. The knowledge created depends on the tools that have been used; therefore, this research contributes to knowledge that is embedded in drawing. This artistic research is not simply a question of looking for information in a different place or time with different tools, but of learning to see in a different way by creating new conceptual models, which like all models are always provisional and should never be treated as final.

Chapter Three

On Drawing Practice in Science

Introduction

This chapter is presented as two articles which have been published in *Leonardo* Journal and therefore follows a different format to other chapters. The inclusion of the following published material is in compliance with University of the Arts London guidelines.

This chapter emerged out of my observations of the differing roles of drawing as a way of knowing in natural science and mathematics whilst artist in residence in two scientific institutions: The Natural History Museum London and Imperial College London. Through this experience, I realised a discrepancy between the role of drawing in natural science and in mathematics which provided a valuable starting point for this research. In natural science, I observed that drawing was assumed to hold greater value as a finished object (a published image) rather than as a research process. It was apparent that natural scientists related to drawings as objects. The first article 'Endangered: A study of the declining practice of Morphological drawing in Zoological Taxonomy'[1] (Anderson, 2014) looks at drawing as process within natural science, specifically the field of Zoological Taxonomy. This study relates to Daston and Galison's concept of the 'idea in the observation' (20010: 58) a definition that I pick up and expand in the later chapters of this thesis.

The first article uncovers a declining culture of drawing within zoological science revealing individual accounts of the epistemological value of drawing as told by a small number of practicing zoologists. An argument is made to as to the importance of drawing in zoological taxonomy, supported by personal insights into the depth of morphological knowledge shown through the drawings of scientists. This article promotes drawing as a way of knowing for art and for science, and points to the importance of maintaining morphological knowledge as the scientific approach to species diagnosis changes at an accelerated pace.

The second article 'Drawing in Mathematics: from Inverse Vision to the Liberation of Form' (Anderson et al, 2014) makes an original contribution through a discussion of

1 Titled 'Endangered' because drawing as a ways of knowing in natural science is in critical decline

drawing as an epistemological tool in research mathematics through the presentation of an example of a collaboration where the differing logics of the artist and mathematician are treated on equal terms. Drawing is at the forefront of this collaboration, valued as an epistemological tool for art and for science, capable of 'liberating' form and challenging didactic approaches to sharing scientific research with the public.

In mathematics, drawing is used as an important part of many mathematicians' research processes, but interestingly it is often disregarded at the end, leaving no trace or 'object' behind to acknowledge the role of drawing. The second article in this chapter is co-authored with mathematicians. Together, we approach these 'disregarded' drawings (which function as part of research mathematics and provide the main tool for interdisciplinary communication within our collaboration) and place them at the centre of mathematics visualisation and practice. We also reveal how we implement collaborative drawing processes into both artistic and mathematics research; not in a reductionist way, but in a way that highlights form and formation.

Drawing as an epistemological tool

I started this research with an awareness that there were differences in the way that artists and scientists study form. In order to understand the contribution of my own research it became important to be aware of the current status of drawing as a research method in art and in science. Observation is a process in both art and science that is inseparable from our understanding and ordering of the world. In this research I identify observational drawing as an endangered practice in zoological science.

Christophe Hoffman, one of the researchers in the 'Knowledge in the Making' research group (who studied the acts of drawing and note making as epistemological tools) at the Max Planck Institute for the History of Science (Berlin), says '[…] some things need to be put down on paper before you can conceive them' (Hoffman, 2011), while Barbara Wittmann, another researcher, says that drawing '[…] makes it possible to see something that no other technique can reveal' (Wittmann, 2011).

This research was largely inspired by Daston and Galison's *Objectivity* (2007), which discusses historical cases of images as epistemological agents. Daston describes observation as an epistemic genre (Daston and Lunbeck, 2010: 81) with the characteristic of emphasis on singular witnessed events Daston calls 'autopsia' (almost like a post-mortem examination) by a named observer. Observational drawings are often singular witnessed events and can therefore be considered as 'autopsic drawings', but Daston's aim is not to focus on drawing specifically but rather to consider the epistemological value of images in a scientific context and the role of the artist/naturalist/scientist in relation to this.

In the chapter 'Epistemologies of the Eye' (2007) Daston and Galison describe how scientific objectivity must be understood as part and parcel of the scientific self: 'epistemic virtues in science are preached and practiced in order to know the world not the self' (Daston and Galison, 2007: 39). Daston and Galison argue that the epistemic virtues of drawing involve the self, but that at the same time they allow us to articulate objectivity and subjectivity simultaneously. With the introduction of new technologies of visualisation, drawing (in a scientific context) could be considered too subjective to achieve a valid scientific representation because the epistemological process that occurs within the drawing process, in which ideas are discovered in the observation, clashes with the scientific conception of objectivity. The next chapter of this thesis aims to complement Daston and Galison's research by offering a practice-based perspective that explores the role of subjectivity and the process of discovering 'ideas in the observations' (Daston and Galison, 2007) within contemporary scientific drawing practice.

In the book *Representing and Intervening*, Hacking describes how the things that are 'seen' in twenty first century science can seldom be observed with the unaided human senses (Hacking, 1983: 168) and reflects on the nature of observation with the aid of a microscope. Hacking discusses the importance of microscopy to our view of the world and knowledge of nature. He says we have a different kind of vision of nature with microscopes and reflects on the difficulty of comparing the macro and microscopic vision. Hacking opens a philosophical space for intervention within the practice of microscopy, saying 'you learn to see through a microscope by doing, not just by looking' (Hacking, 1983: 189) and 'we do not see through a microscope - we see with one' (Hacking, 1983: 207). These new worlds within worlds that the microscope reveals to us are explored in this first study.

I have discussed the relationship between observation and decision making in drawing and microscopy with Dr.George Littlejohn, a plant scientist at Exeter University[2]. He highlighted the parallels and shared history between drawing and microscopy:

2 I had a series of meetings with Littlejohn at Exeter University in 2014.

> Each, when done with consideration, slow the practitioner down to carefully observe, process information and make judgments about what should be recorded. Many modes of microscopy aim to recapitulate the outcome of drawing three-dimensional structures and all require value judgments to be made in the process. Drawing and sketching are very powerful tools in developing close observational skills, probing our own understanding of observed phenomena and communicating that to others (George Littlejohn, 2014, personal communication).

Littlejohn's reflections evoke Ian Hacking's question: 'Do we see with a microscope or through one?' – and reiterate that microscopic vision is not passively looking through a microscope at a view, but actively selecting what you are looking for and what you want to represent. In this research, principles of selection vary depending on the research question, which relates to Thierry de Duve's view that any artwork is nothing other than a 'sum of judgments' both historical and aesthetic, stated by the artist in the act of artistic production' (1998).

In light of Littlejohn's comments I considered the work of Gerhard Scholtz, a contemporary morphologist at the Humboldt University, Berlin, who uses a modern camera lucida microscope to draw his zoological specimens. Scholtz asks his students to draw from the microscope and reports that there is a reluctance to do this. He says it is normal for students to take a digital image from the microscope, but emphasises that drawing enforces a longer observation of the specimen and a different knowledge of the specimen:

> Drawing simplifies the subject e.g. cell structure into abstract shapes which translate the subject into a more informative image than a digital photograph (Scholtz, 2011)[3].

Scholtz told me about zoologists at the NHM who use Camera Lucida microscopes to draw specimens, and with this lead, I began research for the first article presented in this chapter 'Endangered: A study of the declining practice of Morphological Drawing in Zoological Taxonomy'.

3 Transcribed From Wednesday, 10 August 2011 Meeting with Dr Gerhard Scholtz at Humboldt University, Berlin

Endangered: A study of morphological drawing in zoological taxonomy

Morphological drawing has long been the backbone of biological taxonomy. Recently, however, this drawing practice has fallen, almost undetected, into critical decline. At the Natural History Museum (NHM) in London, a small group of zoologists practice morphological drawing with the aid of camera lucida devices. This article evolved out of a series of conversations and interviews with four of these zoologists and seeks to illuminate and illustrate the idiosyncratic and artful drawing processes of each, emphasizing the value they attach to morphological drawing. To gain deeper insight into the scientists' work, I also consider my experience of drawing with a camera lucida device. Reflection on this experience reveals the epistemological value of each individual's morphological drawing and forms an argument for the recognition of morphological drawing as an invaluable scientific and artistic practice.

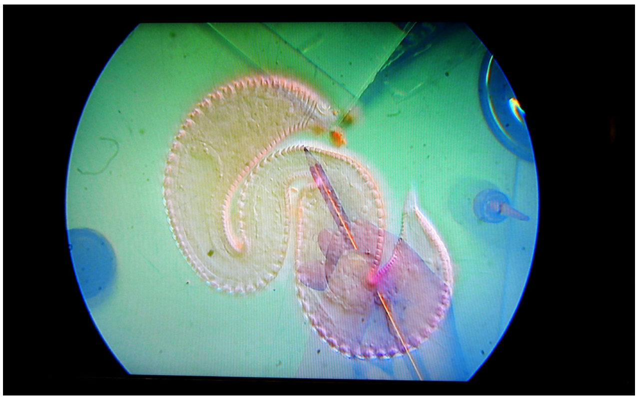

Figure 1.
ANDERSON, Gemma, 2012 camera lucida view of microscopic nematode specimen (© Gemma Anderson)

Taxonomy is a science that identifies, describes, classifies and names living and extinct species; morphology is the study of the form and structure of organisms---both their external appearance and the internal parts such as bones, organs and musculature. This article focuses on morphological drawing utilizing the camera lucida, a microscope-mounted device that performs an optical superimposition of the object being viewed onto the drawing surface. Both object and drawing surface can be viewed simultaneously, as in a photographic double exposure, enabling the draftsman to trace the outlines of the microscopic object (Fig. 1). Drawing with the aid of a camera lucida microscope is a taxonomist's art. As a taxonomic institution, the NHM probably has more camera lucida devices than any other organization. However, as fewer taxonomists are drawing, microscope companies are no longer producing camera lucida devices and, due to lack of funding, universities are no longer producing pure taxonomists. Indeed, taxonomists have been identified as an endangered profession (Pearson, 2011). Over the last 20 years, morphological analysis as a taxonomic tool has been eclipsed by DNA and genomic analysis. As a consequence, the practice of observational drawing of specimens has declined. David L. Pearson makes clear the argument for maintaining morphological taxonomy, but nowhere is there an argument for maintaining the specific practice of drawing within taxonomy.

The scientists presented here all have photographic techniques, scanning electron microscopes (SEMs) and DNA sequencing laboratories at their disposal. Although they often combine results obtained from these technologies, they consistently choose drawing to describe and represent new species.

Two key figures who have informed my understanding of the lineage of the current practice of morphological drawing are Linnaeus (1707-1778) and Goethe (1799-1832). Linnaeus developed the revolutionary system of scientific naming, binominal nomenclature, which persists to this day and is the system used by each of the scientists featured in this paper. The term morphology was coined by Goethe, one of the great Enlightenment polymaths. The term developed out of his intensive study of botanical forms – as in his *Metamorphosis of Plants* (Goethe, 2009) – which is also evidence of his capacity to combine scientific and artistic observation. Goethe may have used a camera lucida device for drawing, as it came into use in about 1807. Linnaeus, working earlier, may have used a grid system to ensure accuracy. While drawings made before the use of the camera lucida device can be appreciated for their aesthetic qualities, those made with aid of the device are valued particularly for their accuracy and repeatability.

Why draw?

The four zoologists I spoke with – Rony Huys, Greg Edgecombe, Natalie Barnes and Tim Ferrero – each describe diagnostic features and name species based on the morphology of specimens. All are studying previously unexplored habitats and seeking new and unobserved species.

Rony Huys studies copepods, microscopic crustaceans found in most oceanic habitats. Copepods are so abundant that there could be as many copepods in the oceans as there are stars in the universe. Huys has discovered a plethora of species with features and characters that no one else has described. He began to group his species into taxa, which led to delineation and diagnosis of new families. Huys examines whole-body copepods with a magnification of 100x. His work has been noted by the international scientific community, and colleagues send him copepods from unusual habitats such as subterranean caves and hydrothermal vents for analysis. Huys recalls the excitement of discovering a particular species collected from an anchialine cave---an unusual habitat with a subterranean connection to the sea and brackish water near the surface. Such habitats have extraordinary faunas, some of which are refuge species from the ice age.

Huys's first drawings of the specimens were detailed, but because he used only one pen size he found that they did not reflect the functional morphology of the specimen[1]:

> There is actually a structural hierarchy in the morphology of copepods, especially when you look at the body and the appendages that are articulated or segmented. These can be armed with setae and or spines, which are often ornate. So the different levels of organization can be enhanced and emphasized by using different thickness of Rotring pen nibs to produce the lines (Huys, 2012, personal communication).

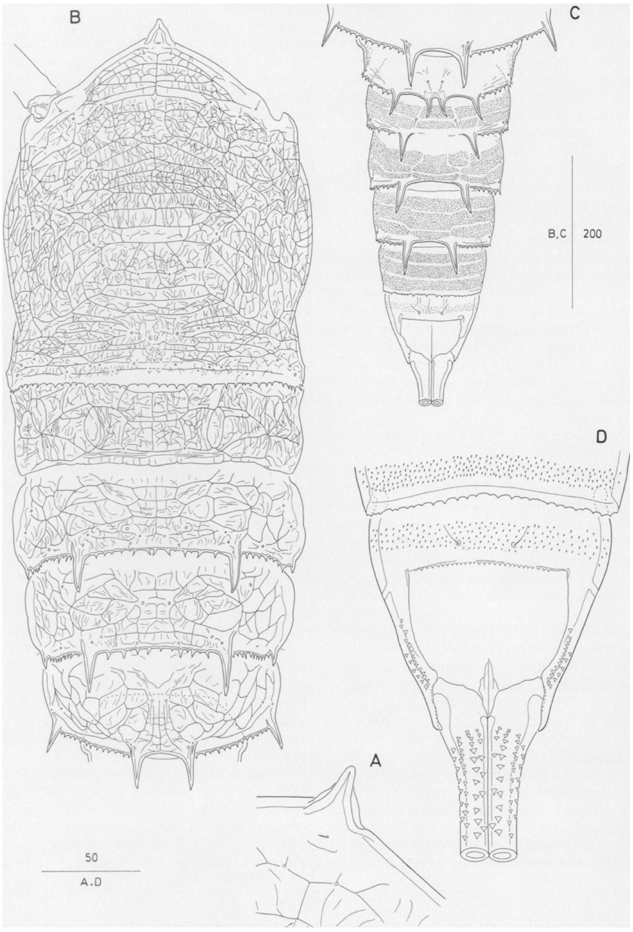

Figure 2.
HUYS, Rony, 1999 Drawing of Andromastax muricatus, Rotring pen on paper.
(© Rony Huys)

1 All quotations of Huys, Edgecombe, Ferrero and Barnes are derived from interviews and conversations with these scientists at the Natural History Museum, London, 2012

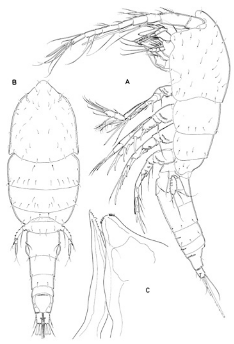

Figure 3.
HUYS, Rony, 1999 new genus of Aegisthidae (Copepoda: Harpacticoida) from hydro-thermal vents on the Galapagos rift, Rotring pen on paper (© Rony Huys)

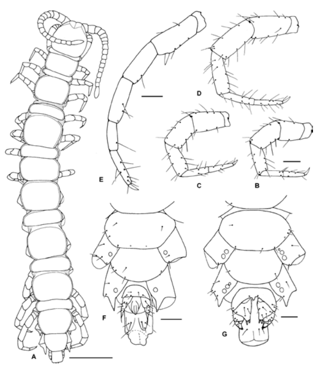

Figure 4.
EDGECOMBE, Greg, 2004 Dichelobius etnaensis, Rotring pen on paper. (© Gregory Edgecombe)

Incidentally, Huys's favorite pen nib size is 0.18 mm, because he can control the nib to produce lines of different thickness (Fig. 2)[2].

Huys's drawing practice not only reflects this structural hierarchy. It also highlights functional morphology such as body segments, which can telescope, and spines, which function as sensory organs to allow organisms to move. Most copepodologists do not draw the articulating membranes between appendage segments; this was a feature that Huys introduced in his unique approach to drawing. When I asked him, 'Why draw the specimen? Why not just take a photo down the microscope?' Huys replied, 'Well, copepods are very three-dimensional, and it's impossible to condense all the information in a single photo, even with confocal microscopy'[3]. In transforming a three-dimensional object into a two-dimensional drawing, Huys uses all sorts of tricks, such as a dotted line to indicate that a margin is behind a feature or introducing gaps between crossing lines in order to make the drawing stand out and create the illusion of three dimensions. Huys observes the animal in dorsal aspect and then turns it around to examine the lateral aspect (Fig. 3)[4]. In doing so, Huys says, he fails to fully represent the three-dimensionality of the specimens, but his solution is to make a number of drawings from different angles. The result is drawings that contain so much understanding and information that it is impossible to imagine how many pages of text it would take to convey the same content.

2 Originally published in CONROY-DALTON, Sophie. and HUYS, Rony. 1999 "New Genus of Aegisthidae (Copepoda: Harpacticoida) from Hydrothermal Vents on the Galapagos Rift," *Journal of Crustacean Biology*, 19 (2), pp. 408-431

3 In confocal microscopy, the animal is reconstructed based on a series of laser photographic sections.

4 Originally published in CONROY-DALTON, Sophie. and HUYS, Rony. 1999 "New Genus of Aegisthidae (Copepoda: Harpacticoida) from Hydrothermal Vents on the Galapagos Rift," *Journal of Crustacean Biology*, 19 (2), pp. 408-431

The unapologetically subjective Greg Edgecombe

When I asked him whether he felt the drawing process was subjective, Greg Edgecombe replied, 'Yes, it is unapologetically subjective, you are steering the reader towards features considered important.'

Greg Edgecombe is a systematist who investigates the evolutionary relationships between the major groups of arthropods. His approach involves a combination of morphological and molecular data and integrates fossils with evidence from living organisms. His taxonomic work is on centipedes. Edgecombe often reorients the antennae of his centipedes so that they fit within the space of the page. When drawing fossils that were originally soft-bodied organisms, meaning that the original anatomy cannot be clearly discerned, Edgecombe endeavors to steer the viewer toward seeing biological structures and not the geological artifact. He employs a selective process that determines how we 'see' the object and claims that this process can be repeated. Edgecombe's practice provides evidence that scientific objectivity can work in tandem with artistic subjectivity. His subjective decisions do not make the work 'unscientific;' they actually enhance the utility and epistemological value of the work (Fig. 4)[5].

One of Edgecombe's favorite things about drawing is that 'it looks beautiful.' This is because he feels drawings are 'true' to his subject. The majority of specimens that Edgecombe draws are 'type' (or name-bearing) specimens, and he needs to look closely. Drawing, Edgecombe says,

does force you to look at all the taxonomically important details and make decisions about exactly what is going on. We draw because the diagnosis includes characters and we really want to understand them. Drawing, more than photography, forces you to confront what is going on, every time.

In contrast to the drawing culture of fine art, taxonomists consider continuity between drawing styles a good thing and encourage copying one another's drawing styles. As Lorraine Daston and Peter Galison write: 'Epistemic virtues in science are preached and practiced in order to know the world, not the self'' (Daston and Galison, 2010: 59). Consistency in the stylistic language of drawing allows for a direct comparison between

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5 Originally published in EDGECOMBE, Gregory D. and GIRIBET, Gonzalo, 2004 "Molecular phylogeny of Australasian anopsobiine centipedes (Chilopoda: Lithobiomorpha)", *Invertebrate Systematics*, 18, pp. 235-249

studies without having to reexamine specimens. One of the drawing techniques that Edgecombe has developed is stippling, which he uses to indicate membranous parts to distinguish them from the harder, more pigmented parts. Approaches to stippling are individual, but Edgecombe's style has been influenced by two morphologists in particular: Eason, who also worked with centipedes (Eason, 2003), and Edgecombe's 'drawing hero' Luis Pereira (Fig. 5) (Pereira, 2007).

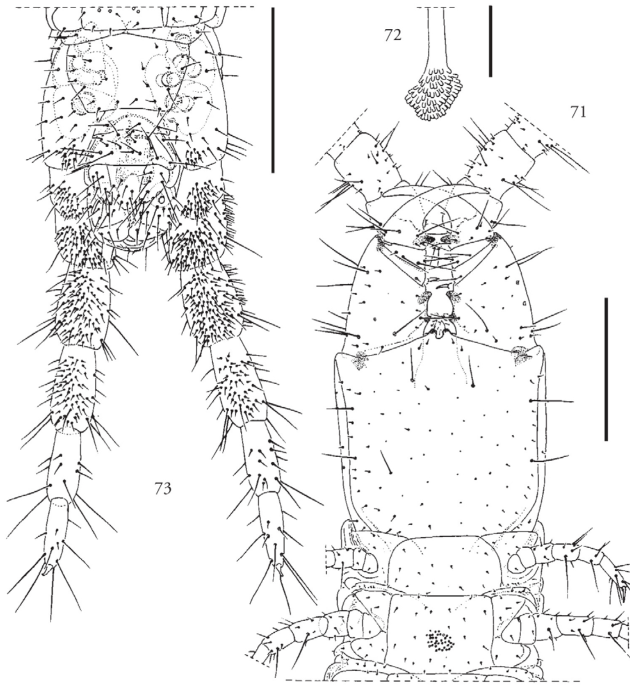
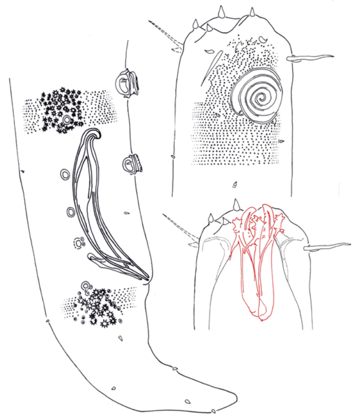


Figure 5.
PEREIRA, Luis, 2006 Plateurytion heurtaultae, Rotring pen on paper. (© Luis Pereira)

Drawing is not timetable-able

Observational drawing using a camera lucida involves intense concentration in a meditative space, without interruption. It also demands practiced hand-eye coordination, analysis, delineation, abstraction and improvisation. One of the merits of drawing over photographic or molecular technologies is that the time spent observing the specimen evidences the perceptual learning process. As the object is delineated, it becomes comparable and consistent with the history of the visualization of the scientific object through drawing. The observer's perception of the object itself is a process of thinking as a transition from experience to judgment, from insight to application. The kind of meditative space needed is increasingly constrained as scientists strive to meet deadlines for publications and write research applications for funding. As Edgecombe's career has successfully progressed, he describes his working life as having become 'far more distracted---when I think back to the times when I produced many drawings, I would have whole days where no one disturbed me, whereas now it is hard to find a free hour; quality time for drawing is getting ever shorter.' Ironically, despite its status as a taxonomical institution, the NHM does not fund pure taxonomy and considers drawing an expensive method.



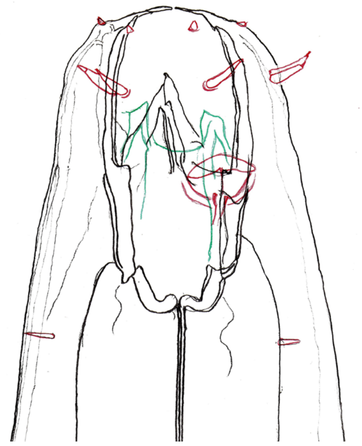


Figure 6.(a+b)
FERRERO, Tim and BARNES, Natalie, 2011
Unpublished figures of marine nematodes, Natural History Museum, London, U.K.
(© Natural History Museum)

Natalie Barnes, Tim Ferrero and the Nematodes

Natalie Barnes and Tim Ferrero study new species of nematodes. Four out of five living organisms are nematodes, and they inhabit a significant part of the Meio fauna (a group of organisms larger than microfauna but smaller than macrofauna). Scientists have studied and drawn nematodes since 1880 – a history that allows morphological characters in contemporary morphological drawings to be compared with historical drawings in order to verify the diagnosis of the organism in question. As scientific knowledge accumulates, the function of drawing increases; as the scope for comparison increases, new drawings breathe life into old ones.

It takes about 10 years of developing observation and microscopy techniques to know which characters are important and to become an expert capable of defining a species. Ferrero describes this process as 'a dynamic balance between similarity and dissimilarity.' He discussed the case of the species *Cheironchus* (Fig. 6), which has two enormous mandibles shaped like something between a grappling hook and a knight's mace (N.B. the colors differentiate characters in different focal planes). This is a predatory animal and DNA analysis would put it in the correct family/genus of predatory animals, but the morphology of those mandibles really gives an insight into the hunting behaviour of the animal – basically it is an ambush predator that uses its large mandibles to grab on to prey and hold on tight. Similarly, it's only when you see the shape of the epsilonematidae nematode that the true nature of its inchworm ambulatory behaviour can be clearly understood (Ferrero, email exchange, 2012). This is evidence of the epistemological value of Ferrero's morphological observations.

The Artist and the Camera Lucida Microscope

Aside from its scientific value, morphological drawing is also of great interest to artists. Goethe's *Metamorphosis of Plants* (Goethe, 2009) and Haeckel's *Radiolarian Atlas* (Haeckel, 2005) both offer studies of comparative morphology, and their work continues to influence artists today. Morphological drawing compiles a visual encyclopedia of the forms of life. To discover a new species is to discover new anatomical features; the latter adds to the zoological vocabulary of form, which the artist, in turn, can articulate through line. Unfortunately the drawings of morphologists are kept in museums, laboratories and libraries and can be difficult to access. Artistic experience and interpretation of these morphologists' drawing process is an important aspect of this study. The following is an account of my experience of drawing at the NHM:

On 9 December, Greg set me up at his camera lucida microscope at the NHM. A new genus and species of scolopendrid centipede from the Australian desert was the specimen offered for observation. At first, my ocular gaze could not "find" the camera lucida; it took a couple of minutes to locate the correct portal through which to view.

I was reminded of Hackings musing: 'We do not see through a microscope, we see with one. But what do we see?' (Hacking, 1983: 208). Once found, the specimen, the hand and the drawing tool are visible – it is quite magical. I had to resist my instinct to draw as I normally would, relying on my own estimations and decisions; rather, I found myself tracing the shadow of the ghost-like specimen, which the superimposed view of my own hand could pass through.

I chose to draw straight onto copper (Fig.7); I prefer the quality of line that can be achieved with copper etching and I wanted to reposition the subject within the significant history of etching and engraving in the natural sciences.

In the next experiment, switching the camera lucida off, I drew, unaided, activating the natural rhythm of my line. Interestingly I started drawing pores, which Greg said he would not draw, as they are not taxonomically important, but Rony would draw, as he considers every feature of taxonomical importance. Like Rony, I was interested in drawing all observable morphologies. I began to perceive morphologies that would not emerge in a photograph. I share Barbara Wittmann's belief that 'drawing makes something visible that no other technology can make visible' (Wittmann, 2011). I found myself perceiving and visualizing new ways to compare forms, each observation opening a possible new route of comparison. Although my unaided drawing is not 100% morphologically correct, it conveys my perception and understanding more than the camera lucida drawing.

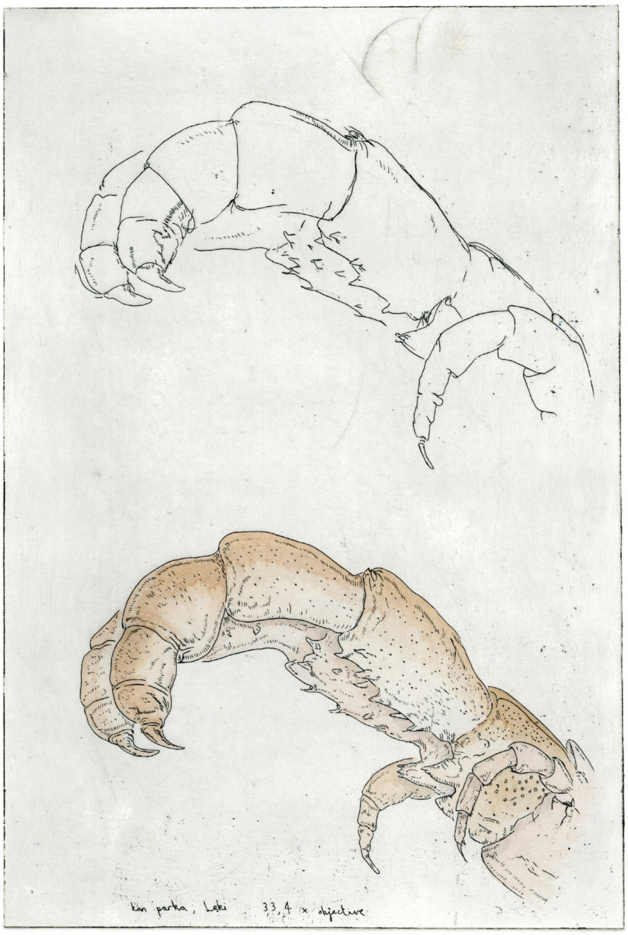


Figure 7.
ANDERSON, Gemma 2012 Kanparka leki (Leg) (species named by Waldock & Edgecombe, 2012), drawn with (above) and without (below) camera lucida device, copper etching, Japanese inks,. (© Gemma Anderson)

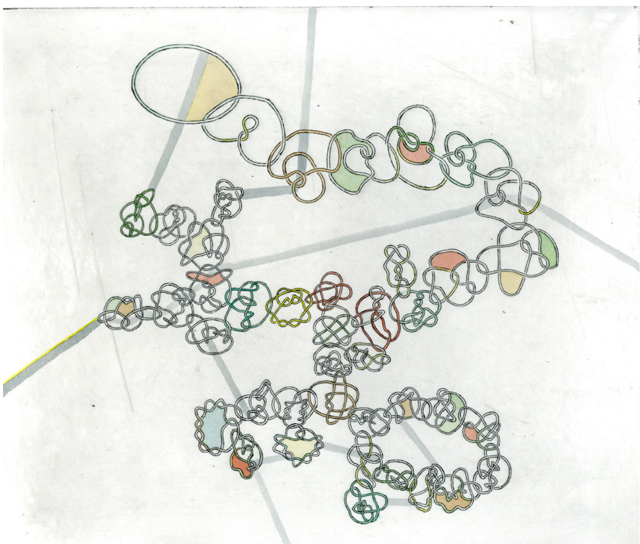


Figure 8.
ANDERSON, Gemma, 2012 DNA knot topology, copper etching, Japanese inks. (© Gemma Anderson)

I returned to the NHM on 26 January, with an appointment to draw nematodes with Natalie Barnes and Tim Ferrero. Nematodes are very three-dimensional. When drawing through the lens of the microscope, I constantly focused in and out as features exist at different ranges of vision. I quickly adopted the following method: focusing on one range and drawing features that appeared significant, then focusing on next layer, drawing, and so on. It became clear that there are so many structures on so many layers that it would be impossible to show an organism's entire morphology with a photograph. (Also, being preserved in alcohol, the specimen loses its color). Nematodes have radial, bilateral and tri-radial symmetry, with pocket-like structures and much triangular biology. Drawing a nematode felt comparable to attempting to observe a mountain range from above, drawing each level of altitude, its geological features and the whole mountain in focus.

It is essential to my own process of drawing to focus on the morphology of each part of the specimen and to abstract this into a linear shape. Play and a process of free association must enter the work. While drawing I compared the main body of one of the nematodes to an accordion tube, as it was concertina-like; the theatrical snake-like headdresses, insect-like ornamental setae and the curling of the nematode bodies in knots reminded me of SEM images of the topology of DNA (Fig. 8 and Fig. 9). In the act of observation, I developed new comparisons between the specimens' forms. Through drawing I could also compare nematodes to Japanese knotweed and placental growth. I test these by interchanging morphologies (i.e. by drawing the nematode in the form of a DNA knot). In this drawing process, I am operating with my imagination, both telling the truth and lying at the same time. The value of direct observation for my own work as an artist lies in formal discoveries that create new groups of imaginative associations that can be further developed through drawing.

DNA Encroaches: The new dawn of taxonomy

As new modes of 'knowing' encroach upon the field of taxonomy, we are witnessing a significant shift away from visual observation. With the explosion of digital photography in the last decade and digital manipulation of images via software such as Photoshop, many scientists who used to draw now use these time-saving technologies alongside or instead of drawings. The introduction of scanning electron microscopy and DNA analysis means that, in some cases, a bar code identifies a new species and the morphology of the specimen remains unobserved. Eventually, this process could result in species being identified with a molecular formula or a number and without a binominal name.

Figure 9.
ANDERSON, Gemma, 2012 Nematode viewed through a camera lucida microscope, copper etching, Japanese inks.
(© Gemma Anderson)

DNA analysis was initially called 'DNA fingerprinting,' implying that each animal has its own distinct signature. However, DNA sequencing is only a part of an organism's fingerprint, and only part of its individuality and 'uniqueness.' Nevertheless, it is not uncommon for molecular biologists to consider only the molecular data without any other knowledge of the species. Quentin D. Wheeler identifies this disconnection as a problem: 'Much data may be collected but what is lost is the greater understanding of what those data mean or don't mean' (Kipling, Mishler and Wheeler, 2005:849). One limitation of a solely molecular delineation of a species is that fewer investigators are likely to test it with their own observations on the putative diagnostic characters. Barnes recounts examples of papers wherein molecular details define species, but where the author cannot define or describe the morphology. She believes that if more observation and morphological work took place, there might not be the need for such extensive molecular work.

Today, almost any laboratory can do DNA analysis, as it is becoming easier and cheaper to generate sequences. It is also common for scientists who work with DNA and molecularly defined species to think it is unnecessary to draw anything. In the last 10 years, Huys has started to combine morphological and molecular research. Interestingly, he points out that the results of a molecular analysis can challenge his ideas based on morphology alone. In such cases he has to return to the specimen and reexamine its characters. He now believes that DNA analysis and morphological analysis can illuminate each other.

Here DNA sequencing becomes a very useful tool, but, being molecular, it also has its limitations. The computer program does not always read correctly, which allows room for error. Barnes observes, 'DNA analysis is subjective and can be less reliable than a drawing.' Molecular biologists are realizing that they need morphology, because if there is a mistake with the DNA data, only the observational knowledge of the morphologist can resolve the issue.

DNA analysis is also combined with scanning electron microscopy. While these technologies appear to be removing the necessity for drawing, both Edgecombe and Huys believe that the combination of the old technology of morphological drawing and the new technologies of DNA analysis and SEM provides a more complete understanding of a species.

Edgecombe started to use SEM combined with morphological drawing in diagnostic papers of type specimens about 10 years ago, but he has never published a drawing of a specimen that he has also imaged in SEM. One reason is that Edgecombe draws specimens wet (preserved in alcohol), to preserve internal anatomy and to ensure that future generations of investigators can check them as wet specimens. Although it is possible to use SEM with uncoated specimens (the Natural History Museum has an environmental SEM), Edgecombe prefers the sharpness of images of specimens that have been coated. He has SEMed uncoated specimens at the NHM and describes the results as 'okay, just not as good, or sharp, or bold. . . . It is a perfectly fine option if you really don't want to dry or coat a specimen (a historically important type specimen, for example) but to my eye the coated specimens look better on the SEM.' Conversely, when Edgecombe images a specimen through SEM technology he dries it and prepares the specimen with a gold-/palladium-coat. Edgecombe will not draw coated specimens because they lose some of the information, most notably pigmentation.

I treat the specimens separately. I have the 'same' information in drawings and SEMs all the time, often even in the same standard orientation, but the image is always created from different specimens. My intent is to double up the amount of information by showing two different specimens in available page space instead of the more nearly redundant information that would apply were I to show the same specimen by two different illustration techniques.

This 'doubling up' can be seen in Fig.10[6], a drawing of the female gonopod of the species *Dichelobius etnaensis* and an SEM image of another female gonopod of the same species. SEM brings further understanding to the analysis, but it does not replace drawing. Edgecombe compares the two images: 'The drawing depicts the overall morphology most clearly, but the SEMs bring extra detail, such as what the surfaces look like.' Photography has its advantages, but drawing remains the sole technology that can detail and clearly show diagnostic features in focus simultaneously.
The current general consensus is that a species diagnosis that includes anatomical information (as can be conveyed via drawing) is more useful than papers that only use photography or DNA analysis. However, for many in the latest generation of taxonomists, who have not developed a morphological drawing practice, diagnostic methods are restricted to SEM and DNA analysis. It is a great idea to combine DNA analysis and morphological drawing, but the question is: Will this younger generation know how to continue the practice of drawing in taxonomy?

6 Originally published in EDGECOMBE, Gregory D. and GIRIBET, Gonzalo, 2004 "Molecular phylogeny of Australasian anopsobiine centipedes (Chilopoda: Lithobiomorpha)", *Invertebrate Systematics*, 18, pp. 235-249

Conclusion: Morphology plays catch-up

With the realization that a species cannot be fully defined without knowing what it looks like, some funding bodies are now more aware of the need to support morphological taxonomy. Although some education programs (for instance the M.Sc. program in Systematics and Biodiversity at the NHM and Imperial College) recognize the importance of morphology, there remains a critical gap due to underfunding over the last 30 years. Taxonomy has been viewed as an old-fashioned science, lacking in innovation, but this is not true---the innovation and range of imaging technologies are evidenced in this paper. However, molecular biology is more attractive and has attracted better funding from the government because its goals are often linked to economic interests, immediately achievable and visible in the short term. Taxonomy is a fundamental science, and it is hard to see the long-term results quickly, but this does not mean that its significance can be overlooked.

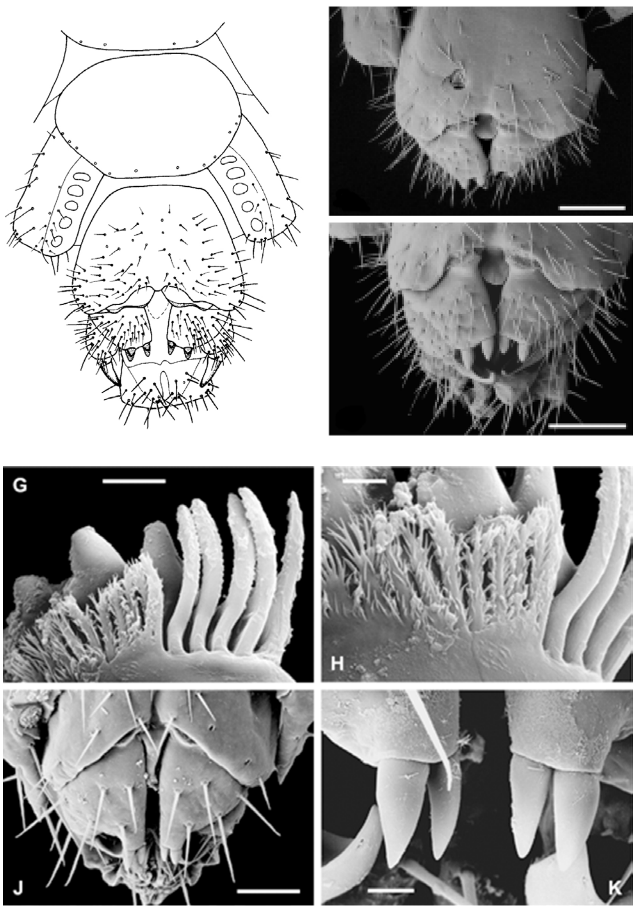


Figure 10.
EDGECOMBE, Greg, 2004 Aciculae and fringe of branching bristles on mandible of Dichelobius etnaensis, Rotring pen on paper and SEM imaging. (© Gregory Edgecombe)

Without the observations of morphologists, which allow us to visually distinguish between species, we could lose an appreciation of the meaning of flora and fauna. The meaning of life lies within the morphology. Edgecombe, Barnes, Ferrero and Huys have spent decades accumulating the perceptive language expressed in their idiosyncratic and uniquely subjective drawing practices; each mark they make is a code and a communicator, visually accessible to an international audience of scientists.

The practice of drawing shapes the mind, and it is often within the time and space of an observation of a specimen that a realization or even a revelation may occur. Drawing is an intimate, devotional act of wonder at the many forms and puzzles that species present. To draw is to know a specimen in a unique way. To study a drawing by Edgecombe, Barnes, Ferrero or Huys is to understand each scientist's view, priorities and work. In Ferrero's words: 'A drawing shows you what you have seen and understood, and it shows this perception and understanding to the viewer.' The ideas conceived by the zoologists through the act of observing are expressed in their observations. If the practice of drawing does not continue in taxonomy, we will lose the richness of these careful observations, and the richness of these minds who know, and have a deep connection to, the species they observe. Furthermore, to discontinue morphological drawing is also to deprive artists of a formal language to be drawn upon. There is no compulsion for drawing to continue alongside DNA analysis, scanning electron microscopy and photography, but perhaps there should be. The debate now is about how best to combine different diagnostic techniques, whether via DNA sequences or via morphological study, the latter including drawing. Each has its own epistemic values and each is a model of taxonomic truth.

This is a time when science and art need each other for support. If the epistemological value of drawing can be recognized within a wider scientific and cultural context, and if we can, in the words of Max Brodel, 'teach the scientist more art and the artist more science' (Brodel. 1908: 477), morphological drawing may survive.

Drawing in Mathematics: from inverse vision to the liberation of form

Gemma Anderson, Dr Dorothy Buck (Imperial College London), Dr Tom Coates (Imperial College London) and Prof. Alessio Corti (geometer, Imperial College London)[1].

'Thinking is really the same as seeing.'
William Thurston, mathematician, 1946–2012

There has been much written, in the pages of *Leonardo* and elsewhere, on the connections between mathematics and art – on mathematical forms in works of art and as aesthetic objects, on the influence of higher-dimensional and non-Euclidean geometries on many artists, and on computer visualization in both mathematics and art[2]. We address here a vital gap in this discussion, describing the role of drawing in the *practice* of mathematical research and in the mathematical creative process. We argue that the shared roles of drawing in mathematics and the visual arts – drawing as a fundamental mode of understanding, and drawing as language – make possible a new mode of collaboration between artists and mathematicians, in which the different logics of the two disciplines coexist on equal terms. We describe our own collaboration, in which drawing-based dialogue, and drawing as a way of knowing, play essential roles. For the artist, the collaboration gives access to beautiful and otherwise inaccessible geometries and the opportunity to experience and transform them, integrating them into her knowledge of form. For the mathematicians, the collaboration allows a new form of creativity, giving material form to purely conceptual objects, and brings their research to a wider audience in a non-didactic way. Together we develop a new visual vocabulary, drawn directly from contemporary mathematical research but stripped of all technical meaning. The mathematical forms and geometries are thereby liberated: freed from their original context and open to new understandings and interpretations.

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1 I proposed this collaborative article in 2012, after which I coordinated the writing process and co-authored each section of this article. Tom Coates described my contribution as 'Gemma's contribution to our joint work "On Drawing and Mathematics" was essential. It is hard to say now exactly who is responsible for each of the ideas in the paper because it was a genuine collaboration: the ideas described there were created and refined in hundreds of conversations between the four authors of the paper, during Gemma's residencies at Imperial College London. Mathematics doesn't have a system of "lead authorship" on papers -- we order authors alphabetically, rather than in a way that signifies their contribution to the work -- but nonetheless it would certainly be correct to describe Gemma as either lead or co-lead author on the paper' (Tom Coates, 2015, personal communication).

2 See for example: Johnson, 1972; Pickover, 1988; Leonardo, 1992; Emmer, 1993; Melvin and Hewison, 2005; Kalantari, 2005; Mandelbrojt, 2006 and Sinclair et al, 2006.

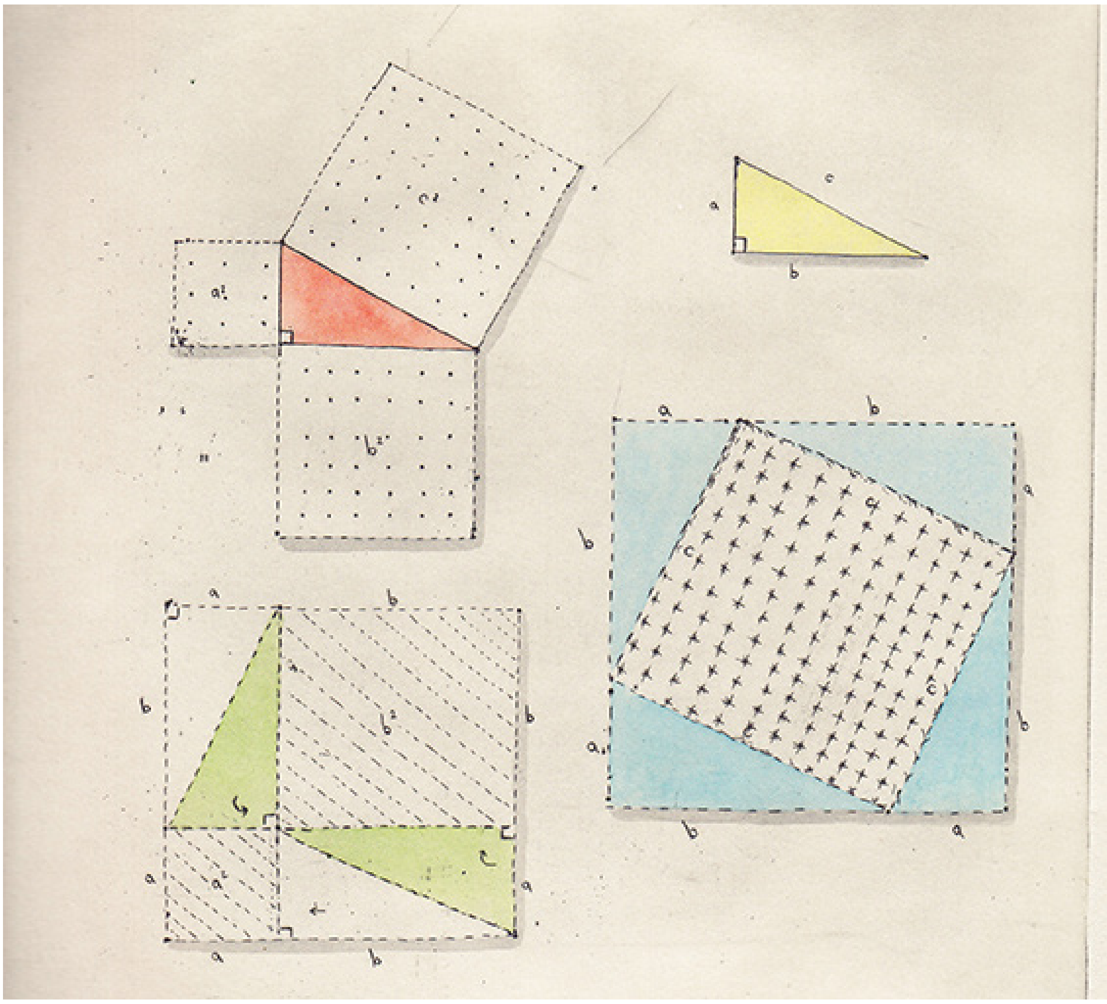

Figure 11.
ANDERSON, Gemma, 2012. The Theorem of Pythagoras. Copper etching, hand coloured with Japanese inks, (© Gemma Anderson)

Linear logical thinking and mathematical proof

We begin by introducing, by means of an example, a mode of thought that is fundamental to mathematical practice. This is what we call *linear logical thinking*. The paradigmatic example of linear logical thinking is mathematical proof. This will be important later on, when we describe mathematical creativity as a dialogue between two characters, the Thinker and the Drawer. The Thinker exists in the world of linear logical thinking.

A proof in mathematics is a logical demonstration that some statement is true. Starting from something that is known to be true we make a sequence of deductions, each following unassailably from the step before, that leads to the desired statement. We illustrate this with the famous Theorem of Pythagoras:

1. 'In right-angled triangles the square on the side opposite the right angle equals the sum of the squares on the sides containing the right angle.' (Heath, 1956)

In other words, if the sides of a right-angled triangle are of lengths a, b, and c, as shown in Figure 11(i), then $a^2 + b^2 = c^2$. Let us prove this[3].

Consider a square with side-length $a + b$, partitioned as shown in Figure 11(ii). One shaded square (the smaller one as shown) has side-length a, hence area a^2. The other shaded square has side-length b, hence area b^2. The total shaded area is therefore equal to $a^2 + b^2$. Each of the four triangles is right-angled, and the sides adjacent to the right-angle have lengths a and b; thus in each case the hypotenuse (the side opposite to the right-angle) has length c. Thus, each of the four triangles is a copy of that shown in Figure 11(i).

Now consider the same square, partitioned in a different way as shown in Figure 11(iii). Once again, each of the four triangles is right-angled with sides a,b,c, and thus is a copy of the triangle in Figure 11(i). In particular, therefore, the length of each side of the shaded square is c, and so the area of the shaded square is c^2. Yet the total shaded area shown in Figure 11(ii) must be equal to the total shaded area shown in Figure 11(iii), for they are each equal to the area of the large square (a square of side-length $a + b$) minus the area of four copies of the triangle from Figure 1(i). It follows that $a^2 + b^2 = c^2$ .QED.

3 This proof, which we gave as an example of linear logical thinking, is drawing-based. Drawing-based mathematical proofs are rare, and indeed only occur in certain sub-fields of mathematics. The types of argument that are considered acceptable in a mathematical proof have varied throughout history and vary across the different parts of mathematics; drawing-based proofs are (and were) accepted only at some times and only in some contexts. There are delicate questions of mathematical philosophy lurking here—what *precisely* do we mean by proof? A lucid account of these issues, and a spirited defense of visual reasoning in mathematics, can be found in Brown, 2008. For a discussion of diagrams and visualizations as explanations, see also Henderson and Taimina, 2006

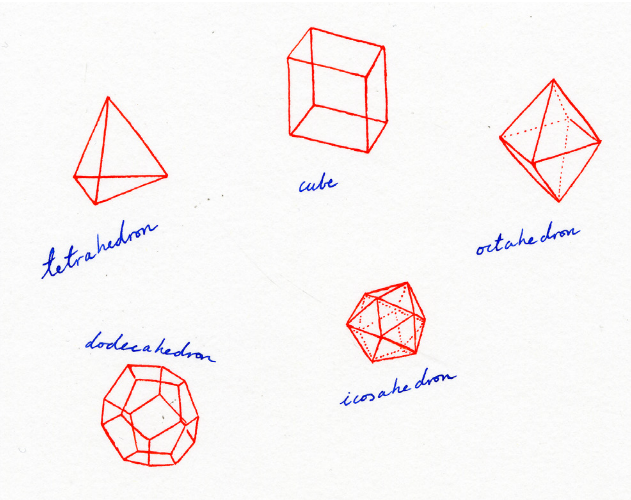

Figure 12.
ANDERSON, Gemma, 2012. The Platonic solids. Pen on paper. (© Gemma Anderson)

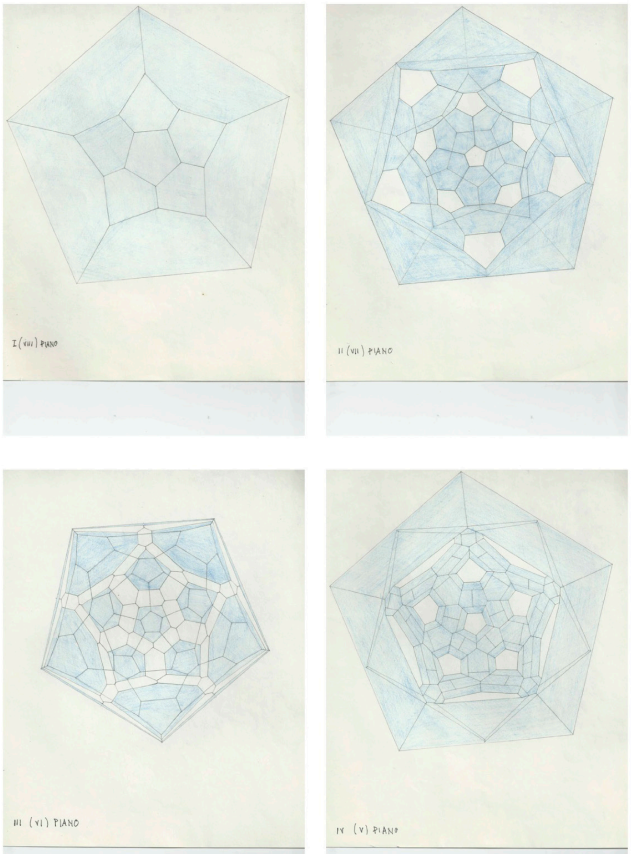

Figure 13.
CORTI, Alessio, Circa 1980. Sketches of a four dimensional solid, the 120-Cell, made of 120 dodecahedra. Pencil on paper. (© Alessio Corti)

Drawing as inverse vision

The drawing that we will focus on in this essay is the drawing of imaginary objects, that is, objects that we see with our mind's eye. Whether the drawn object be physical or imaginary, all drawing is a sort of *inverse vision*[4]. By drawing with pencil on paper we give physical form to our mental images, and in the process we learn to see them better. Thus, in this context, drawing is a tool to train ourselves better to see imaginary things.

We illustrate this by showing some drawings made by Alessio Corti as a teenager. There are 5 regular (or Platonic) three-dimensional solids, shown in Figure 12. Having read somewhere that in four dimensions[5]there are 6 regular solids and that one of them is made of 120 regular dodecahedra, Corti tried to prove this fact using the Euler formula in four dimensions and could not do it. Eventually he decided that the only way for him to prove the existence of this 120-cell was to draw it (Figure 13)[6].

The imaginary objects that are seen with inverse vision are visual objects: they may not have material form, but nevertheless they can be visualized. Thus the drawing that we speak of here is the drawing *of visual objects*. There has been much written about the visual and spatial representation of *non-visual* scientific objects: on the visualization of statistical data, for example, or on the visual representation of processes and of relationships between concepts[7]. These involve quite different forms of drawing, and we do not consider them here.

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4 Thurston (1994) writes: "People have very powerful facilities for taking in information visually or kinesthetically, and thinking with their spatial sense. On the other hand, they do not have a very good built-in facility for inverse vision, that is, turning an internal spatial understanding back into a two-dimensional image. Consequently, mathematicians usually have fewer and poorer figures in their papers and books than in their heads." (ibid., p.164)

5 For a mathematician, to say that a shape is two-dimensional means that each point of the shape can be described using two co-ordinates (x,y). For example, the surface of the Earth is two-dimensional because any point on the surface of the Earth can be represented by two numbers: latitude and longitude. The space in which we live is three-dimensional, because a point in that space can be represented by three co-ordinates (x,y,z). Similarly, points in four-dimensional space are described by four numbers (x,y,z,t). In Einstein's Theory of Relativity, the fourth co-ordinate t here is taken to represent time, but in our context there is no need to insist on this. We cannot experience or perceive four-dimensional space in the same way that we do three-dimensional space, but nonetheless we can conceive of and reason about it.

6 The 120-cell is constructed in layers. We begin with one dodecahedron (I), and then successively add more dodecahedra by gluing along pentagonal faces (II, III). Image IV is half-way through the construction: we have added 60 dodecahedra.

7 See, for example, Tufte's magisterial work on statistical visualization 1983, also 1990, 1997;Lynch, 1985; Hankins, 1999

Drawing in mathematical creativity

Now that we have said a little about what we mean by thinking, and a little about what we mean by drawing, we are ready to examine the use of drawing in mathematical research as a channel for intuition and creativity. This use of drawing is hidden: rarely spoken about among mathematicians, and undiscussed in the literature on drawing. This absence of discussion is surprising, given how widespread the practice is in research mathematics, even in those sub-fields that frown on drawing-based proofs.

New mathematics does not start life as perfectly formed, rigorously proved theorems. A fundamental part of the creative process in mathematics is the passage from intuitive, imaginative understanding to rigorous, formal proof. This process is not a one-way transformation: we can think of it as a dialogue between two characters, let us call them the Thinker and the Drawer. The Thinker operates in the world of linear logical thinking and of mathematical proof. The Drawer operates in the world of the imagination and of inverse vision.

On the one hand, drawing gives the Thinker a way to organise thoughts. By listening to the Drawer, the Thinker is led to choose a sequence of logical steps that reflects the Drawer's inner vision. Thus the Drawer helps the Thinker to overcome otherwise unmanageable complexities. On the other hand, the Thinker's geometrically apt rigorization[8] helps the Drawer to focus and sharpen the inner vision, and the dialogue continues.

To make this concrete, consider the drawings and text in Figure 14[9]. This is a calculation of a certain transformation, called a "monodromy transformation", which measures the twisting of a shape as you move around a loop in the parameter space for that shape. Here the monodromy transformation is given by the matrix (table of numbers) labelled by "T" on the second page of the calculation. The drawings and text are the last of a sequence of drawings, each recording a few exchanges in the dialogue described above. The process is incremental and iterative: one has a first go at it, one makes a

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8 See Goresky and Macpherson (1988: 22). Historically, in geometry, there has always been a tension between imagination and rigour. *Stratified Morse Theory* is a major contribution to the notoriously ill-founded field of Differential Topology. Goresky and MacPherson develop drawing-based methods of mathematical proof and, in the Introduction, stress the importance of rigorization that is geometrically apt. Our own interpretation of this process is the dialogue between the Thinker and the Drawer.

9 This is the last in a sequence of drawings and calculations, with each step in the sequence representing improved understanding. The entire sequence records a dialog between the Thinker and the Drawer.

mistake and then has a second go at it, and so on. Each drawing (and calculation) in the sequence is better and truer to its object than the previous one. The final outcome, shown in Figure 14, can be read in two different ways: as a visualisation of the monodromy transformation, and as a proof that the monodromy transformation is indeed given by the matrix "T".

There is an interesting point of methodological similarity between Anderson's artistic process and this aspect of drawing in mathematics[10]. Even when drawing naturalistically Anderson, like mathematicians, draws abstract objects, that is, objects that she sees with her mind's eye. For her, drawing often functions as pre-linguistic and pre-mathematical form of intuition and abstraction in which drawn objects, although often derived from the observable world, become abstract forms. This is in close parallel to the role of the Drawer in the mathematical creative process.

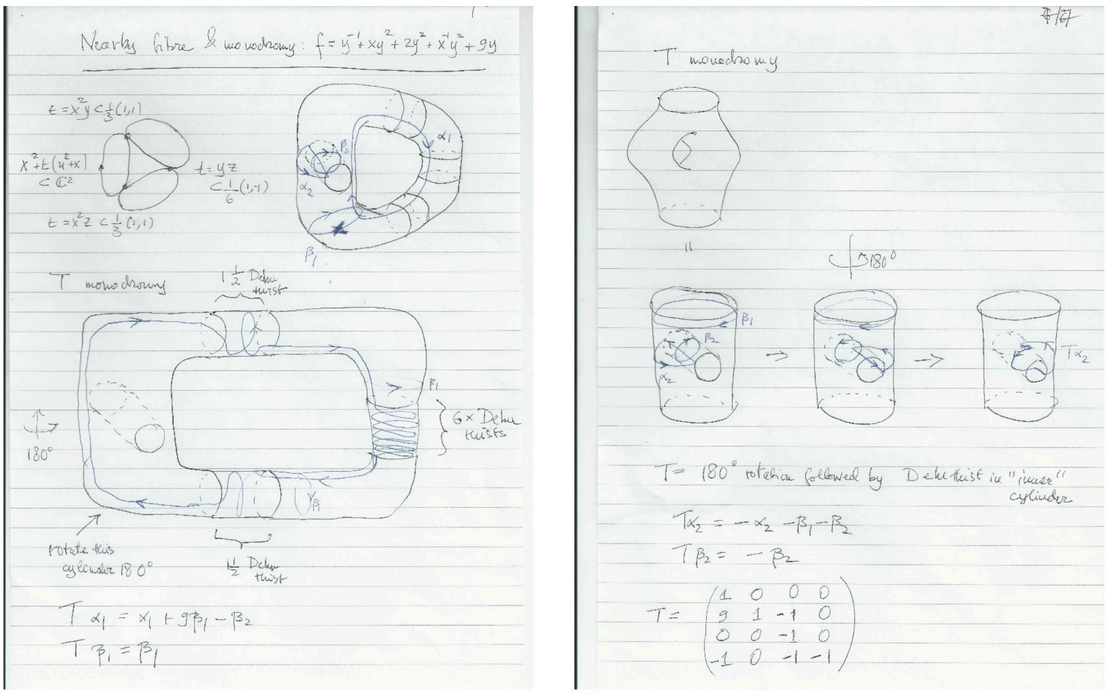

Figure 14.
BUCK, Dorothy. 2012. Drawings that convey mathematical intuition. Pencil on paper.
(© Dorothy Buck)

10 This similarity undoubtedly holds for many other artists as well. But it certainly does not hold for all artists, as many contemporary visual artists simply do not draw.

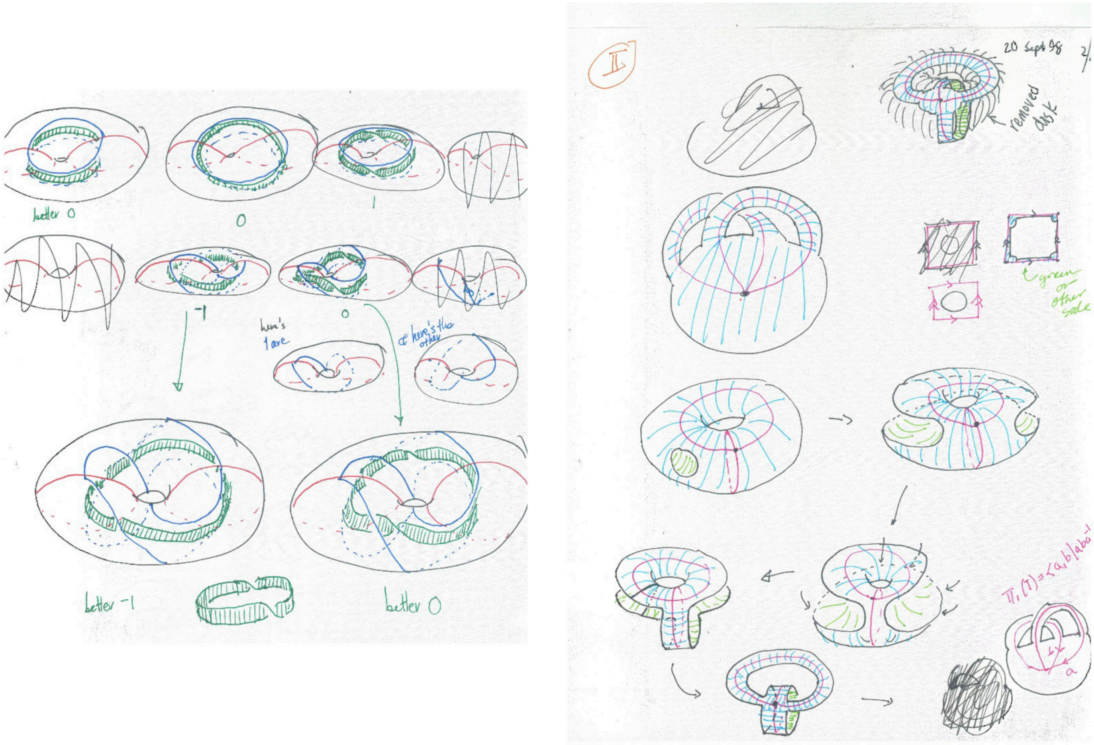

Figure 15.
BUCK, Dorothy and unnamed mathematical collaborators, 2012. Topologists' working drawings. Pen and pencil on paper.

The use of drawing to channel mathematical intuition shares another, more essential, aspect with Anderson's artistic process. In each case, the process of drawing and the reflection that accompanies it *transforms the drawer*, changing the way in which they know and understand the object that is being drawn. This explains why drawing is so much more effective, in this context, than the use of computer-based visualization software: it is the act and experience of drawing itself that creates intuitive understanding.

<u>Drawing and communication</u>

We have discussed the role of drawing in mathematical intuition, and in the translation of that intuition into formal mathematical argument. Drawing also plays a key role in the communication of intuition between scientists: both between mathematicians and as part of interdisciplinary research.

Dorothy Buck is a topologist (a mathematician who studies shape and space) and also a mathematical biologist. Topologists sketch freely, both to develop their own intuition and to communicate that intuition to others. Figure 15 illustrates an example of this: drawings produced by Buck and a colleague – together, whilst conversing, each adding to or altering the drawing in turn – when trying to understand how two complicated surfaces intersect[11].

These drawings have far less precision than the text and professional vocabulary in a typical mathematical research article, but they allow Buck and her colleague to share and develop the essential kernel of the ideas involved. In fact the lack of precision here is an advantage: the ability to highlight mathematically interesting aspects while suppressing unimportant detail makes drawing a more useful tool than, for example, faithful computer-generated imagery.

Drawing is also essential in communication between topologists and molecular biologists. Because the professional vocabulary of both of these fields is highly technical, and because topologists and molecular biologists typically share no technical training, drawing serves as a vital bridge between the two disciplines. Drawing is the first language for developing questions and ideas; indeed, sharing intuition in mathematical-biological collaboration may not be possible in any other way. For example, Buck and her molecular biologist collaborators often consider how DNA molecules become knotted and linked during cellular reactions such as replication and recombination (see Figure 6). Rather than introducing technical vocabulary and defining many terms, they draw how the central DNA axis twists and deforms during these reactions, thus immediately communicating the essential information[12].

The liberation of form

We turn now to our ongoing collaboration, and the artwork that we have made together. The collaboration began in February 2011, when Anderson saw the images in the Imperial College Newsletter article 'A Periodic Table of Shapes'[13]. This article introduced Coates and Corti's research program, which concerns geometric forms called Fano Varieties. Fano Varieties are atomic pieces of mathematical shapes, and

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11 The first focuses on how a particular surface (the twisted green band) intersects other objects on a torus (the surface of a donut). The second illustrates how one can deform a punctured version of the torus. The drawings capture essential geometric information while obscuring some irrelevant technical detail.

12 This shows particular sections of DNA molecules that will later interact to form knots. The colours suggest the biological interaction: matching colours denote which subsections will be joined. The rest of the DNA structure (other sections and more detailed molecular representations) is suppressed, so that the knotting reaction is highlighted.

13 "Periodic Table of Shapes", 2011

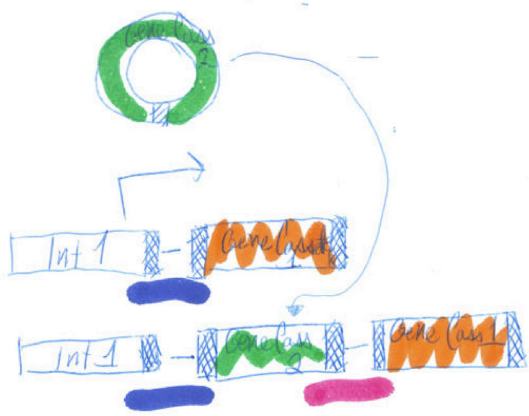

Figure 16.
BUCK, Dorothy and unnamed biological collaborators, 2012. Working sketch while planning a series of experiments. Pen and pencil on paper.

Figure 17.
Computer generated images of some three-dimensional Fano Varieties

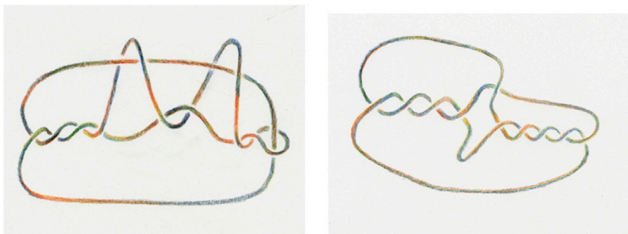

Figure 18.
ANDERSON, Gemma, 2012. Two drawings of the same mathematical knot.

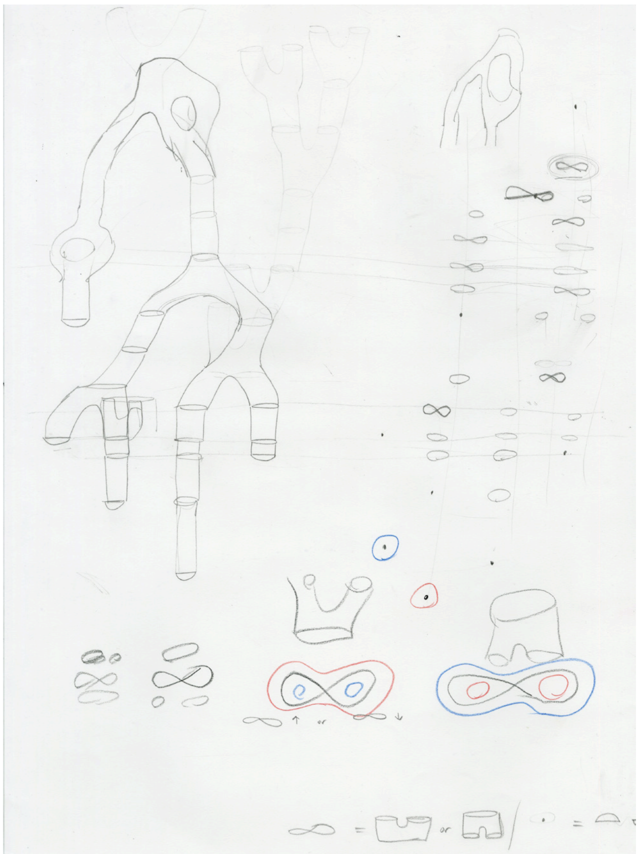

Figure 18.b.
ANDERSON, Gemma and CORTI, Alessio, 2012. A collaborative drawing made by Anderson and Corti when discussing Morse Theory, a part of topology.

the goal of Coates and Corti's program is the classification of Fano Varieties in 4 dimensions[14]. Figure 17 reproduces some of the images originally contained in that article. The precise definition of a Fano Variety—given in the Glossary—is a technical matter in mathematics and is not so important here; we encourage the reader to look at the images in Figure 17 purely *as images*, just as Anderson did, and not as mathematics.

Anderson is a visual artist whose practice is crucially informed by a longstanding interest in drawing and classification in the natural sciences. She was initially attracted to the unfamiliar, mysterious forms of the Fano Varieties purely as images. She was fascinated by the sense that these geometries exist in a world outside the physical world, and she was struck by the fact that mathematicians still lack (after almost a century of effort) a satisfactory system of classification for these forms. She took the article back to her studio and began to make drawings, exploring the forms, merging them, and organizing them in different ways of her own.

Later this developed into a fully-fledged collaboration, first between Anderson and Coates and then involving all of us. Our collaboration is founded on a shared commitment to drawing as a channel for creativity and imagination, and on a shared faith in the intrinsic power of visual images to reach out to the viewer (be they artist, scientist, or member of the public) in a direct and unmediated way.
Drawing, too, serves a privileged tool of communication between us (Figure 18a[15]+b), allowing us to discuss the essential core of many mathematical and biological ideas despite the fact that we have quite different backgrounds; indeed Anderson has no formal scientific training at all. Our collaboration is still developing and is still very much experimental in character. We briefly describe some of the artwork that we have made together and the techniques that we employed. There are two strands to the collaboration, one centred around the Fano geometries and the other around knots and DNA.

Initially Anderson made an etching of all the rank-1 Fano Varieties, classified by shape and resemblance to one another (Figure 19). We then made models of Fano

14 Coates et al, 2012
15 These are similar to the drawings Buck and her mathematical collaborators would draw during working discussions. The colours used here are chosen for aesthetic reasons, whereas in a scientific setting colours are often used to represent biological properties (e.g. atoms of a given kind or charge).

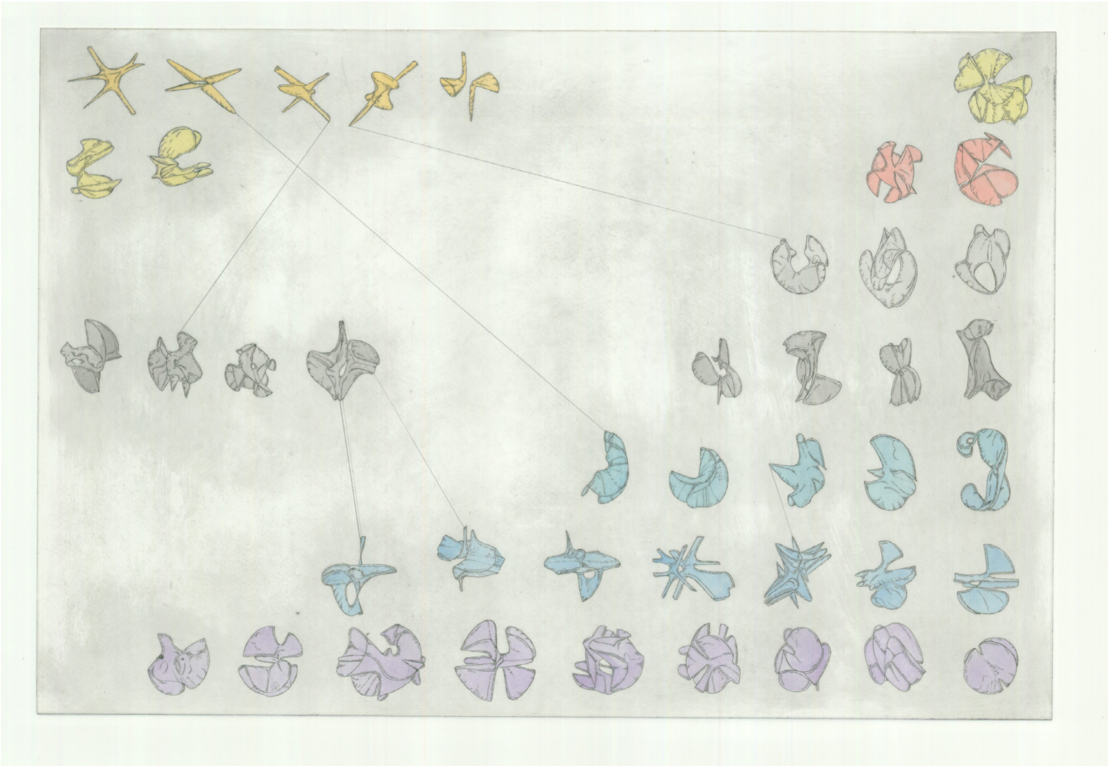

Figure 9.
ANDERSON, Gemma Periodic Table of Fano Varieties, Copper etching and Japanese inks, 2012.

Figure 10.
ANDERSON, Gemma and COATES, Tom, 2012. Sliceform, Laser-cut, hand assembled, Copper Etching.

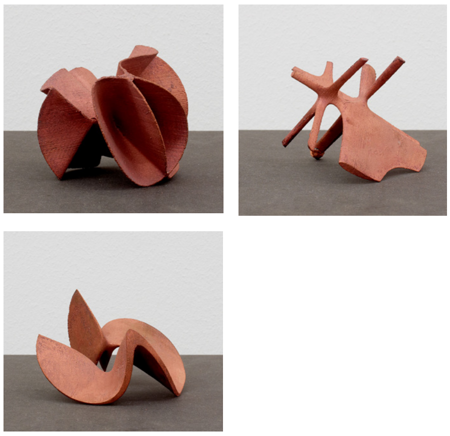

Figure 11(a,b,c). ANDERSON, Gemma and COATES, Tom, 2012. 327 and B4, Copper Investment Casts of RP Forms.

Varieties, both as interlocking paper sculptures called sliceforms[16] (Figure 20), and using 3d printing and casting (Figure 21). To build the models we had to develop new software and algorithms for creating sliceforms from algebraic equations, and also for turning these equations into the thickened polygonal meshes required for Rapid Prototyping. The algebraic equations on which the etchings and models are based were developed in Coates and Corti's research program. The equations were visualised, and certain parameters adjusted, using the open source program surfex. The sliceforms were generated using new code written in *Mathematica*; the equations were turned into .stl and .obj files suitable for 3d printing using *Mathematica*, the open source program meshlab, and new code written in the open source mathematical software language Sage[17]. In building the Fano models we make contact with a long tradition of mathematical model building in the 19th century[18], now largely lost, but we revisit this with the full power of 21st century mathematical science[19] and with a blend of traditional and modern techniques: drawing, etching, painting, casting; Rapid Prototyping, laser cutting, computer algebra, computer-aided manufacture.

In our work on knots, Anderson again began by experimenting, drawing different diagrams of the same knot, as in Figure 8, and different knots. During this process, Buck and Anderson discussed how DNA may be represented, and how selectively highlighting features may aid our understanding of these knotted molecules. Anderson then created three-dimensional DNA knots in different media. For example, she made ceramic knots and links, some with helices as part of their structure, and used a variety of glazing and sketching techniques to highlight the molecular structure. Anderson and Buck together created a detailed drawing of a section of DNA, which Anderson then wove as a jacquard textile that itself can be knotted or linked. Knotted and linked DNA molecules are routinely visualized by scientists through computational simulations (using Metropolis Monte Carlo or Molecular Dynamics methods). This collaboration has produced some of the first artistic representations of these forms.

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16 The paper making up the sliceform of a Fano Variety is etched with images related to that Fano Variety, such as Cayley graphs of the associated modular symmetry groups.

17 Holzer, 2010; Cignoni et al, 2008; Stein, 2012

18 Anderson was inspired by mathematical models in the Science Museum, especially the cardboard sliceform models of ellipsoids made at the Munich Workshops taught by Felix Klein and Alexander Von Brill in the 1870s. Also of inspiration: a model of the cubic surface made by Olaus Henrici in 1875, and paper models from Joseph Alber's Bauhaus preliminary courses (1925-1928).

19 The classification questions that Coates and Corti study have been open since the work of Gino Fano in the 1930s, yet the techniques that they apply—a blend of ideas from geometry, string theory, and high-performance computing—would have been unthinkable even a decade ago.

Our work in context

The advances in computer technology that made possible the Visual Mathematics movement at the end of the 20th Century also make possible the first step in our collaborative process: shared visualization. Yet the work we produce is neither Visual Mathematics[20]. nor, as Max Bill has called for, 'art based on the principles of mathematics' (Bill in Emmer, 1993). On the other hand, there is a long history of artists incorporating mathematical forms into their artistic vocabulary and transforming them through their practice, for example the influence of non-Euclidean geometries on the Russian avant-garde (See Corrada, 1992). Our work continues this tradition, using contemporary computer visualization technology only as an intermediate, if essential, part of our process.

The drawings and models that we have made as artworks are quite different from the drawings that we discussed above. In mathematics drawing is typically an informal process, which is later translated into algebra or text. In Anderson's process there need be no further translation: the drawing is the work.

Throughout the collaboration, our creative process has been almost entirely guided by Anderson. Allowing themselves to be guided by Anderson's artistic vision, the mathematicians in the collaboration gained some unexpected benefits. By giving up the traditional, didactic approach to scientific popularization, they did not have to infantilize, compromise or falsify their ideas. The artworks that we produce are true to the mathematical objects that they represent, even as they carry none of the technical context where those objects originate. The Fano models and knot sculptures give body and weight to forms that had no previous physical existence, and it is precisely by giving these forms a body that is stripped of the original scientific meaning that we can bring contemporary mathematical research to a wider audience in a direct and unmediated way. Through drawing and modeling, the forms are liberated and can exist and function on different levels[21]. No longer constrained by their mathematical meaning, they become accessible to different forms of understanding and appreciation: by artists, scientists, and the wider public.

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20 The mathematics that we describe here is not Visual Mathematics in the sense of Emmer, *ibid*. Some of the authors' research makes heavy use of computers, to generate data and test conjectures, but we seldom use computer-based *visualizations* in our work: computers are used to perform many thousands of algebraic manipulations and to solve equations, not to visualize the complex geometries that we study.

21 'A work of art, therefore, is a complete and *closed* form in its uniqueness as a balanced organic whole, while at the same time constituting an *open* product on account of its susceptibility to countless different interpretations which do not impinge on its unadulterable specificity.' (Eco, 1962)

Conclusion to 'Drawing in Science' chapter

These articles demonstrate how I have cut across practice in two different sciences: one that looks at concrete, found things; and one that most often deals with abstract objects, which cannot be directly experienced. Together these articles show drawing as an epistemological tool in both natural and mathematical science.

I asked my collaborator Professor Alessio Corti to reflect on the nature of mathematical observation; his response has helped me to draw my own conclusions on this subject: 'In short I would insist that the object of study in maths is not the material world (which it is for experimental sciences) - and not everyone, or even every mathematician, would agree with this - but that the mathematical object can be studied by a method that is very close in spirit to the natural sciences […] metaphorically rather than literally/ analogous to the experiment' (Corti, 2015, personal communication). On reflection, the natural scientist's relation to the specimen is very different to the mathematician's relation to the mathematical object and requires different kinds of observation; the first requiring optical observation (source material of the natural/physical world) and the second requiring a kind of conceptual observation where the subject is immaterial. Both of these 'types' of observation are important to this research and will be explored through the subsequent chapters of this thesis.

Chapter Four

Drawing Resemblances and Isomorphology

The 'Isomorphology' research project involves observational drawing of resemblances between animal, vegetable and mineral specimens. It has developed through engagement with scientific institutions and the direct observation of specimens held in scientific collections. As in the natural sciences, in this research, systems of classification are intended to organise information (biological, mineral or animal), and to facilitate the recording and communication of this information[1]. This artistic enquiry into morphological resemblance has uncovered explores an alternative, 'extra-scientific' method of classification – stimulated both by the practice of drawing specimens and by literature that explores the philosophy of classification and the possibilities for alternatives to the standard Linnaean system.

This chapter is in two parts. The first explores drawing as a way of 'making visible' the visual resemblances that are recorded in the Rashleigh mineral nicknames (these minerals are held at the Royal Cornwall Museum). The second reveals how drawing these resemblances led to the development of my own classificatory schema, which I have named 'Isomorphology', and outlines how I have put this into practice at the Natural History Museum, London. This is followed by a more descriptive narrative of the Isomorphology method, and how this has transferred into public workshops[2].

As a whole, this chapter draws support from Foucault's concept of 'Resemblance', as presented in *The Order of Things*, Dupré's argument for a pluralistic approach to biological classification in *The Disorder of Things*, and Lima-de-Faria's cross kingdom classifications in *Evolution without Selection,* which are based on morphological resemblance. To buttress these analyses, examples of pre-Linnaean 'extra-scientific' approaches to classification, including the 'Joke of Nature' and 'Doctrine of Signatures' are explored. I then articulate 'Isomorphology' and propose a visual 'species' concept for this study, which draws on the work of Dupré and Ershefsky. These explorations lead into the chapter's closing discussion of Isomorphology as a concept and practice which can be shared with others.

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1 In recent years scientific taxonomy has moved away from distinguishing species based on morphological features, and towards genetic distinctions through DNA analysis.(Anderson, 2014)..

2 This chapter is supported by an Appendix (A) which provides additional evidence and documentation.

Drawing resemblance: The Rashleigh mineral nicknames

The concept of 'resemblance' and the effort to represent visual connections between otherwise disparate objects has been consistent in my drawing practice since my early years as a student. As this practice developed I realised that it could contribute to morphological understanding in both artistic and scientific contexts, a realisation that led me to develop this project.

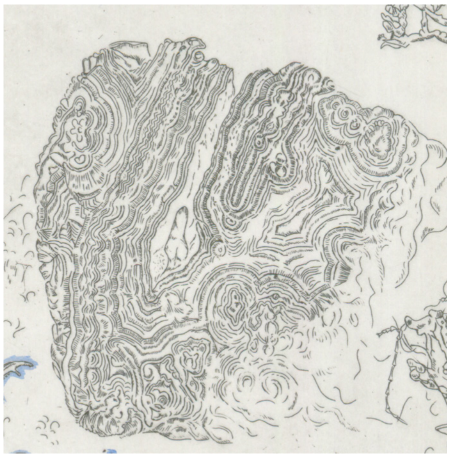
In 2011, while researching in the catalogues of the Rashleigh Mineral Collection at the Courtney Library (Royal Cornwall Museum), Truro, I discovered a curious blend of poetic creation and scientific fact: a number of mineral specimens with nicknames given by Cornish miners based on their resemblance to other natural objects. These minerals and their nicknames became, for me, a means to explore the practice of 'drawing resemblance' and a way to think about extra-scientific systems of classification.

Philip Rashleigh (1725-1811) collected Cornish minerals throughout his life. His collection, housed at the Royal Cornwall Museum, is known for the outstanding quality of the specimens and for Rashleigh's system of cataloguing. In October 2011, I visited the Courtney Library at the Royal Cornwall Museum to consult Rashleigh's mineral catalogue (Rashleigh, 1797). The catalogues were compiled between 1800 and 1810, decades before the Mineralogical Association applied systematic scientific naming to these minerals in the second half of the 19th century.

Many of the minerals recorded were found in the depths of mines like Wheal Gunner and Wheal[3] Towan. As the minerals had not been observed or recorded before in Cornwall, the association of the mineral forms to familiar objects through nicknaming was a useful mnemonic device. Frequently, the descriptions in the Rashleigh catalogues use the term 'resemblance', for example, the miners named a cassiterite specimen 'wood tin' (Fig1.a.), which was then described as; 'wood like tin ore, with fibrous or radiated texture, forming concentric circles like wood, resembling the colour and appearance of wood cut from a knotted tree' (Rashleigh 1797). Based on their own observations of the natural world, the miners projected familiar associations of form on to the unfamiliar minerals.

3 'wheal' being the Cornish for 'mine'

a. .



b.

c..

d.

Figure 1.a.
ANDERSON, Gemma, 2012. Wood tin specimen (Rashleigh Mineral Collection, Truro Museum). Photograph (© Anderson)
Figure 1.b.
ANDERSON, Gemma, 2012. Wood tin specimen (Rashleigh Mineral Collection, Truro Museum). Copper etching and Japanese inks. (© Anderson)
Figure 1.c.
ANDERSON, Gemma, 2012. Wood specimen (Kew Gardens, Bark Collection). Photograph (© Anderson)
Figure 1.d.
ANDERSON, Gemma, 2012. Wood specimen (Rashleigh Mineral Collection, Truro Museum). Copper etching and Japanese inks. (© Anderson)

Figure 2.a.
ANDERSON, Gemma, 2012. (Rashleigh Mineral Collection, Truro Museum). Photograph (© Anderson)
Figure 2.b.
ANDERSON, Gemma, 2012. Flint specimen, 'Mollusc ore' (Rashleigh Mineral Collection, Truro Museum). Copper etching and Japanese inks. (© Anderson)

Based on the archival material surveyed as part of this research, I have created this list as a classification of all the specimens held within the Rashleigh Collection that have been given nicknames:

Wood tin - cassiterite
Beetle ore - clinoclase
Brick (tile) ore - cuprite
Cog–wheel ore - bournonite
Cube ore - pharmacosiderite
Goose-dung ore - ganomatite
Horn silver - chlorargyrite
Horseflesh ore - bornite
Horsetooth ore - siderite
Jack straw crystals - cerussite
Peacock copper - bornite
Ruby copper - cuprite
Sparable tin - cassiterite
Wood copper - olivenite
Toads eye tin - cassiterite
Blister copper - copper

In the process of this research I met Courtenay Smale, a Cornish mineralogist who has studied the Rashleigh Collection. The imaginative nicknames the miners gave to the minerals inspired Courtenay and me to create our own nicknames for other mineral specimens in the collection. For example, I named a flint specimen (Fig. 2) 'Mollusc ore', I also discovered that iron ore was much more wood-like than cassiterite and gave the

3.a.

3.b.

4.b.

Figure 3.a.
ANDERSON, Gemma, 2012. Chalcedony 'Griffin ore' (Castle Caerhays mineral collection). Photograph (© Anderson)
Figure 3.b.
ANDERSON, Gemma, 2012. Chalcedony 'Griffin ore' (Castle Caerhays mineral collection). Copper etching and Japanese inks. (© Anderson)
Figure 4.b.
ANDERSON, Gemma, 2012. Rashleigh mineral nicknames, close up of 'rose ore' (Drawn from Rashleigh Mineral Collection, Truro Museum and Castle Caerhays mineral collection). Copper etching and Japanese inks. (© Anderson)

Figure 4. a.
ANDERSON, Gemma, 2012. Rashleigh mineral nicknames (Drawn from Rashleigh Mineral Collection, Truro Museum and Castle Caerhays mineral collection). Copper etching and Japanese inks. (© Anderson)

nickname 'wood knot ore' to the specimen; further, Courtenay named a chalcedony specimen[4] 'Griffin ore' (Fig.3). This new tranche of nicknames[5], together with the old combine to inspire my own contemporary and visual taxonomy.

I decided to explore the mineral specimens through drawing, focusing on the resemblances the miners recorded in combination with my own, as an ordering principle and basis for constructing an artwork. The artwork was developed through visualising each mineral within an imagined landscape as the object that it is said to resemble. For example, I drew rose ore in the theoretical position of a rose and the mineral (flint) mollusc ore was drawn as an animal (mollusk) populating the rose ore flora. In the etching 'Rashleigh Mineral Nicknames' (Fig.4.a), specimens are drawn and composed on the basis of their resemblances, each specimen poses as the object it resembles, and the mineral material of the specimen may not be perceived by the viewer. The etching indicates that, together, the minerals form a landscape of resemblance.

Visual resemblance organises the relationships between the nicknamed mineral specimens in the Rashleigh Collection and their corresponding objects. Drawing can make resemblance visible through the extraction of the structure underlying the resemblance, which enables structures of the mineral to be exchanged with the animal or vegetable in the image space. This research creates a foundational analogy between morphological structures of composition and observational structures of correspondence. The extraction of morphological information and omission of colour and other visual 'noise' facilitates the comparison of form.

Drawing resemblance requires both the observation of the specimen as a whole (a 'macro' or zoomed-out view), and as constituent parts (a 'micro' or zoomed-in view) (see page 31). In my artistic practice, it is often in a zoomed-in observational view that I begin to abstract the particular into more general structures, simply by noticing the form of parts rather than the whole. Practiced observation then develops this ability to see and relate the general-in-the-particular and a continued drawing practice can articulate

4 From the Williams Mineral Collection at Caerhay's Castle, Cornwall

5 Nicknames added by me and Courtenay:
Rose ore or Desert Rose - gypsum
Griffin Ore - chalcedony
Mollusc Ore - flint
Wood knot ore - iron ore

Figure 5.
PLOT, Robert (1677). Problematic Flint. Engraving (©. Wellcome Trust Image Collection)
Figure 6.
ANDERSON, Gemma, 2012. Problematic flint (Drawn from The Natural History Museum paleontology collection). Copper etching and Japanese inks. (© Anderson)

these general forms and their correspondences in connection with one another.

When drawing the mineral specimen 'wood tin' I observed its resemblance to wood with both a 'macro' view and a 'micro' view of the specimen. After drawing the mineral specimen, I made an appointment with Kew Gardens' bark collection to find a specimen of wood resembling the mineral specimen that I had drawn. Through drawing, I observed that the individual nature of the wood specimen also resembled objects such as minerals and biological forms. These observations, where one thing signals another, imply a 'chain of resemblance' described by Foucault as 'impos[ing] adjacencies that in their turn guarantee further resemblances' (2001: 20).

Problematic flint and the 'joke of nature'

'Nature has joked uncommonly in all the outward appearances of natural things' (Olaf Worm, 1651, cited in Findlen, 1990).

Paula Findlen (1990) outlines the joke of nature or *'lusus naturae'* as instances of natural form identified as 'playing' through wit, rhetoric and imagination. This concept was important to the understanding of natural history during the 16th and 17th centuries when order was often constructed through analogy. The joke of nature provides for horizontal, non-hierarchical relations among natural objects. Attempts made at classifying these 'jokes', which established meaning through a reflexive system of correspondences, include collections and displays in museums and engravings in the period's scientific texts. The terms 'play' and 'joke' had currency in the time's scientific discourse, and these terms were often an integral component of pre-Linnaean taxonomic models[6]. Hence, Worms remark that 'nature has joked uncommonly in all the outward appearances of natural things' (1651).

I explore the concept of the joke of nature using the example of curiously formed flint specimens that resemble parts of human or animal bodies. These specimens, described as 'Problematic Flint' by the English naturalist Robert Plot (1640-1696) are best represented in an engraving[7] (Fig.5) by Sir Thomas Penyston found in *The Natural History of Oxford-shire* (Plot 1972). To investigate Problematic Flint as a joke of nature, I explored specimens that the Natural History Museum still classifies as 'Problematic Flint'[8]. Drawing revealed the humour of these specimens, reflected in the etching 'Problematic Flint' (Fig.6) wherein I have ordered pieces of problematic flint to emphasise resemblances to human and animal body parts.

The etchings 'Problematic Flint' and 'The Rashleigh mineral nicknames' provide an opportunity for the viewer to question their own perception and to ask if the object is foremost mineral, animal or vegetable. Is it fact or fiction? The 'joke' pressures the observer to decide why the resemblance exists, and to ask who or what has made this resemblance. The object can then be observed as part of an analogy, which means that it is both liberated from its pre-existing taxonomy and definition, and it is a potential part of a different definition and, potentially, taxonomy.

Foucault, resemblance and the imagination

Foucault's discussion of resemblance in *The Order of Things* relates to what he calls the Pre-Classical episteme (before Descartes). Through establishing nicknames based on resemblance, the Cornish miners have retained something of this episteme's thought in an era when it was not anymore a dominant mode of knowing in science. I use Foucault's concept of resemblance, being constituted of 'four similitudes', as a tool for defining the resemblances observable in the Rashleigh mineral nicknames.

6 These terms are no longer used in scientific writing.

7 Made in the 17th century

8 Flint is classified as 'problematic' on the basis that is was collected because it resembled another natural object (Jill Darell, Palaeontologist, NHM, personal communication, 2015)

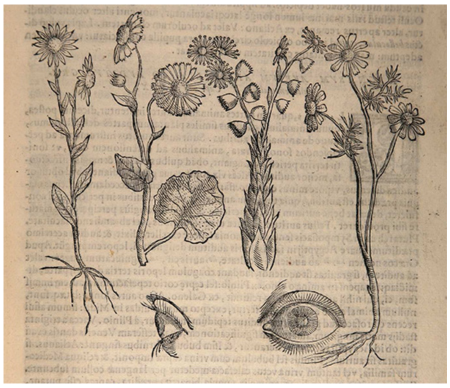
1. Convenience

Found in the adjacency of one form to another – so that in the hinge between two things a resemblance appears (as in the Rashleigh Mineral nicknames). This principle is described beautifully by Aldrovandi:

> Place and similitude become entangled: we see mosses growing on the outside of shells, plants in the antlers of stags, a sort of grass on the faces of men; and the strange zoophyte, by mingling together the properties that make it similar to the plants as well as to the animals also juxtaposes them' (Aldrovandi ,1647: 663, in Foucault 2001: 20).

2. Emulation

Distinct from spatiality, this quality is to do with reflection and mirroring. The quality of emulation exists in the Rashleigh Collection in the sense that one specimen may mirror or reflect another almost as though a puzzle or question and answer. Paracelsus compares this fundamentally binary categorisation of the world to the image of two twins 'who resemble one another completely, without it being possible for anyone to say which of them brought its similitude to the other' (Paracelsus,1573: 3, in Foucault, 2001: 27). With this in mind, the specimens 'wood tin' and 'knot wood' can be thought of as a pair reflecting and rivaling one another.



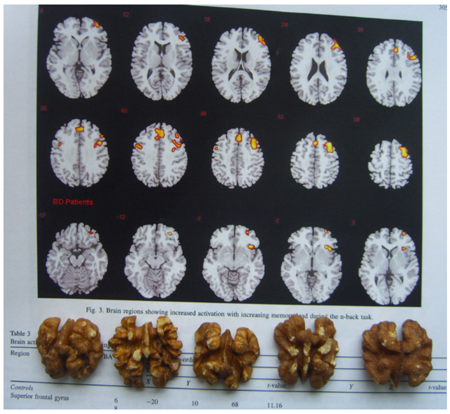


Figure 7.
Unknown, circa 1560, Eyebright, illustration from Baptista della Portas Phytognomica (ref). Woodcut.
Figure 8.
ANDERSON, Gemma, 2012. Comparison of walnut and brain morphology compared to tin specimen (Rashleigh Mineral Collection, Truro Museum). Photograph (© Anderson)

3. Analogy

Analogy makes possible the confrontation of resemblances across space, but also speaks of adjacencies, of bonds and of joints - the resemblance of relations. This polyvalence endows analogy with a universal field of application, 'through it, all the figures in the whole world can be drawn together' (Foucault, 2001: 24). Foucault believed man transmits resemblances back into the world from which they are first received and indicates that analogy is the principle that makes possible the confrontation of resemblances across space and scale. Through drawing, and in the space of the imagination, I can visibly return perceived resemblances to the world from which I have received them. In the 18th century, the miners made analogical comparisons between the minerals and objects they had seen in their locale. The geographic space in which the miners drew analogies was comparatively much smaller than the space possible to draw analogies from today. In my drawings, I have been able to make analogic references to specimens that exist beyond the grasp of the miners' local knowledge; nowadays, globe-spanning resemblances are possible for the Rashleigh Minerals.

4. Sympathy

Sympathy can draw even the most distant of things together into a singularity, as for example 'Griffin ore' which draws a mythological creature and a mineral together via this quality. For Foucault, sympathy is an instance of the same so strong and so insistent that it will not rest content to be merely one of the forms of likeness; 'it has the dangerous power of *assimilating*, of rendering things identical to one another, of mingling them, of causing their individuality to disappear' (Foucault, 1990: 26) and thus of rendering them foreign to what they were before.

To detect a resemblance between natural forms is an important exercise of artistic imagination; it is akin to Leonardo da Vinci's technique of finding analogies and taking inspiration from shapes in clouds or spots on walls (Daston and Galison, 2007). Foucault emphasises the link to imagination when he says 'without imagination, there would be no resemblance between things' (1990: 76). He implies the importance of recall in enabling the possibility of two impressions to appear simultaneously while only one thing is being presently observed. For example, the cloud is present but the thing that it resembles is not, yet the imagination allows both to exist by combining the faculties of observation and recall. This scheme of thought is applicable to the naming of mineral specimens. For example, when I observe the 'mollusc ore' both the mineral (flint) and the animal (mollusc) are present in my imagination simultaneously. Foucault makes this link between imagination and resemblance explicit by proposing that resemblance can only manifest through the imagination, and that imagination can only be exercised with the aid of resemblance: 'there must be in the things represented, the insistent murmur of resemblance; there must be, in the representation, the perpetual possibility of imaginative recall' (1990: 76).

I interpret Foucault's 'mechanics of the image' concept (Foucault, 1990: 77) as an explanation which allows for further relations between modes of representation

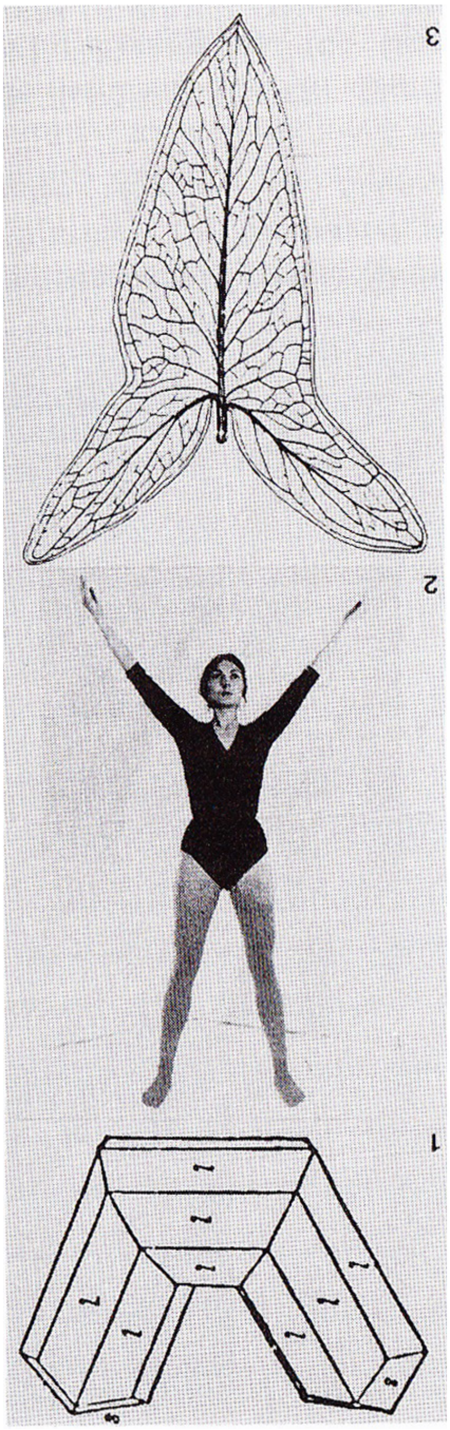


Figure 9.
LIMA-DE-FARIA, (Lima-de-Faria, 1998, Fig.3.1). Collage of photograph and drawing by unnamed artist/author. From *Evolution without Selection* pp.19.

(i.e. drawing). He describes the 'mechanics of the image' as the analysis that occurs through the observation of an object (e.g. mineral specimen) that accumulates as a simultaneous set of comparisons, which is supported by the cumulative nature of drawing; as each drawing builds on previous observations. This process combines the analysis of impressions, of reminiscence, of imagination, and of memory. Further to this, Foucault outlines two stages that the mechanics of the image follow. The first is a 'negative' identification of the apparent disorder in nature and the second is a 'positive' stage of realising a reconstitution of order out of those impressions. In this context the artwork 'Rashleigh's Mineral Nicknames' is an attempt to unify these two stages through a reconstitution of order for the mineral specimens.

Building on the visual orders of others: *Phytognomica* and *Evolution without Selection*

To direct the practice of drawing resemblance towards a more systematic visual order, this research takes inspiration from two distinctive sources: the images of resemblance between the animal and vegetable in Giovanni Battista Della Porta's 16th century *Phytognomica* (1588) and the 20th century images of 'isomorphisms' in Lima-de-Faria's *Evolution without Selection* (1998). *Phytognomica* presents an epistemological scheme that places resemblance as a principle of medical classification based on the 'Ancient Doctrine of Signatures' which states the medicinal uses of plants are indicated by their resemblance to specific human organs. For example, aconite (Fig.7) was thought to cure eye disease, and ground walnuts (which resemble the brain)

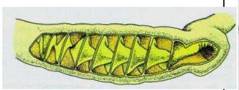
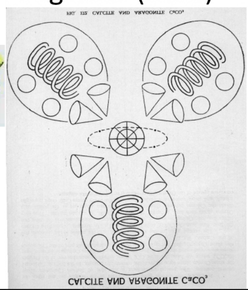
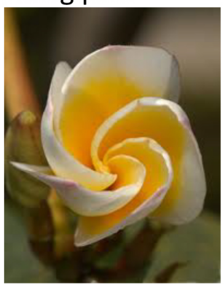
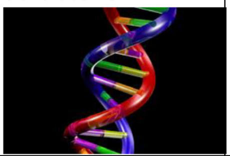
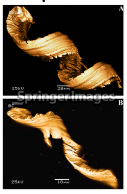
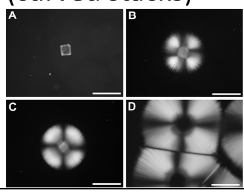
	Animal	Mineral	Vegetable
Spiral/Curve	Valves- Human and Shark 	Aragonite (Shell) 	Frangipani 
	Polypeptide DNA Helical Structure 	Sulphosalt 	Ferns 
	Sheep Horns 	Pure Silver 	Martynia lutea (fruit) 
	Mammoth tusks (Skeleton) 	Chlorite crystals (curved stacks) 	Agrimonia odorata (fruit-hooks) 
	Capra Ibex (European goat-horn) 	Teelite 	Convolvulus 
	Spiroceras, ammonoid (Jurassic)	Cylindrite	Banana Leaves

Figure 10.
ANDERSON, Gemma, 2012. Image of first page of list of Isomorphology specimens. Photograph (© Anderson)

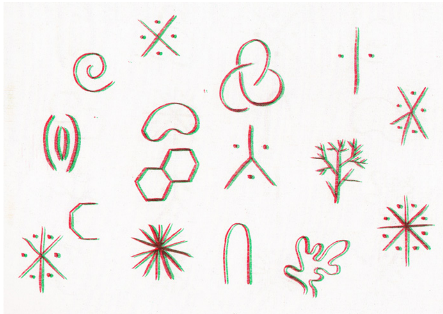


Figure 11.

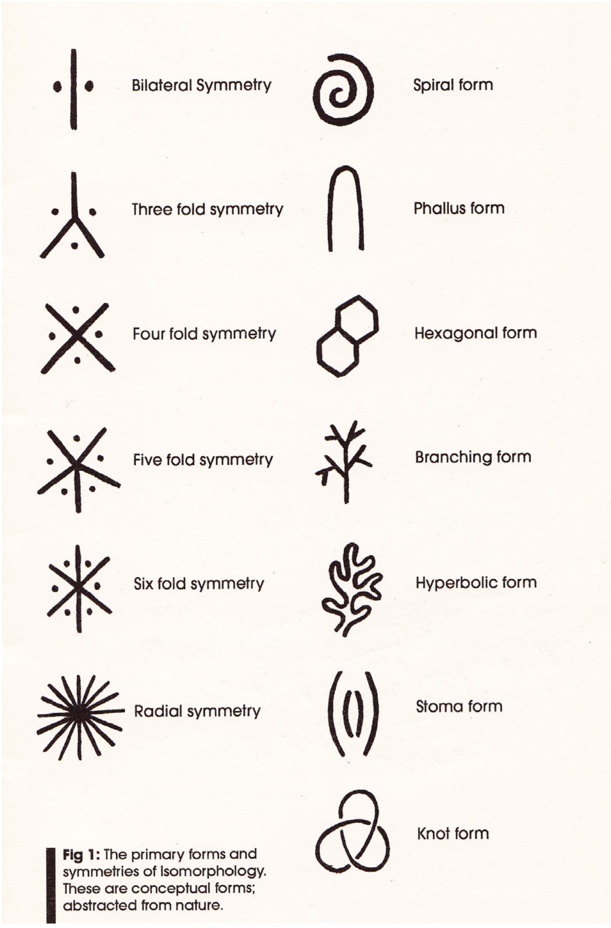


Figure 12.

Figure 11.
ANDERSON, Gemma, 2012. Initial sketch of forms and symmetries of Isomorphology, risograph two-colour print (© Anderson)
Figure 12.
ANDERSON, Gemma, 2013. Visual list of forms and symmetries of Isomorphology, a page from Isomorphology (super-collider version, 2013, c Anderson)
Figure 13.
LIMA-DE-FARIA, (Lima-de-Faria, 1998, Fig.12.4). Five-fold symmetry. Collage of photograph and drawing by unnamed artist/author. From Evolution without Selection pp.159.

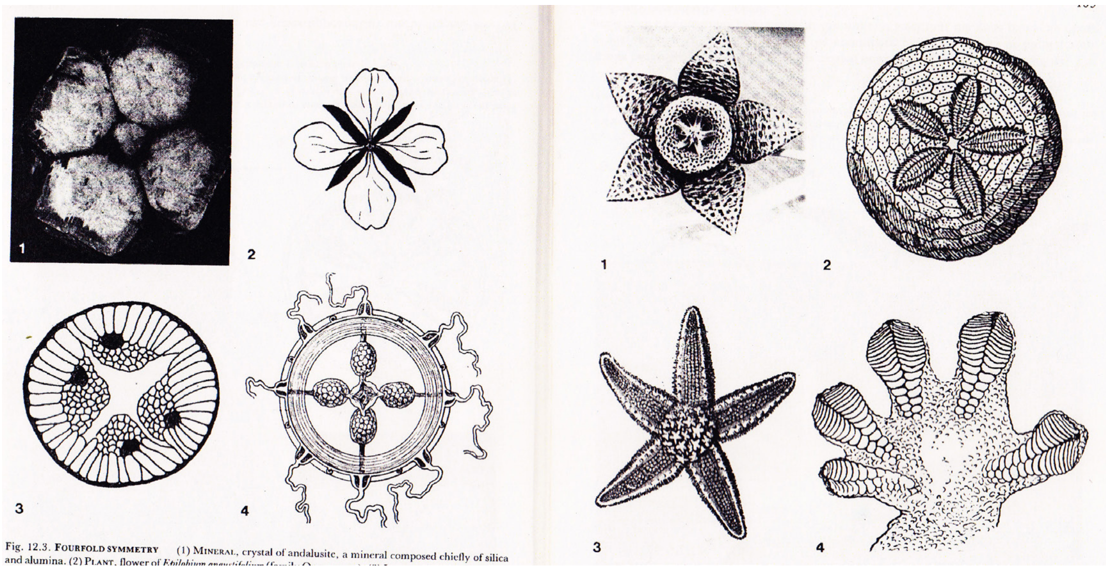


Figure 13.

(Fig.8) were thought to be a base for headache tonics. Daston counts these examples of the doctrine as 'marvels of nature' due to the fact that their mode of operation is hidden from perception, describing these sympathies as 'occult properties' (Daston, 1998: 35-50). The origin of these remedies lies within the observation of a resemblance (based on visual analogy) between the forms of species; or what Paracelsus would call their 'signatures'. Paracelsus wrote that 'God has allowed nothing to remain without exterior and visible signs in the form of special marks, just as a man who has buried a hoard of treasure marks the spot that he may find again' (Paracelsus, 1573: 393, in Foucault, 1990: 30). In *The Order of Things* Foucault credits the concept of 'signatures' to Paracelsus (1491–1541) who is believed to have developed the 'Doctrine of Signatures' as he travelled throughout Europe and to the Levant and Egypt, treating people and experimenting with new plants in search of more cures. Foucault regards the 'Doctrine of Signatures' as occupying an important position in scientific and medical philosophy from the 16th century onwards (1990: 20). He describes 'signatures' as the visible marks (or forms) written in the anatomy of all things, and says 'There can be no signature without a resemblance and no resemblance without a signature' (1990: 29).

I have chosen Baptista Della Porta's text *Phytognomica* (1588) as a reference for the concept of the 'Doctrine of Signatures' because it uses drawing to represent resemblances or 'signatures' between human, animal, and plant anatomies. Through delineation, these drawings make resemblance visible and provide an inspiring example on which this research builds. As my own observations of resemblances between animal, mineral, and vegetable morphologies of field and museum specimens accumulated, I began to imagine a visual scheme, like the images in *Phytognomica,* but extended to also include mineral forms.

In order to establish if others had created documents which included images of resemblances between the animal, mineral, and vegetable orders, I began a search through contemporary and historical literature[9]. This search found studies of 'patterns in nature'[10] which were mainly explored through photography rather than drawing and only one example that addressed specific cross-kingdom resemblances between the animal, the vegetable and the mineral, which was Antonio Lima-de-Faria's *Evolution without Selection* (1998). This text applies 20th century knowledge of chemistry and physics to the study of the microstructure of nature and reveals that disparate classes

9 In the British Library, the NHM library, the Welcome Trust Library and the Royal College of Physicians Library.

10 For example: Ball, P. (2001) *The Self-Made Tapestry: Pattern Formation in Nature.*

of organic and inorganic matter have been found to share important structural qualities. *Evolution without Selection* compiles images[11] found in scientific texts that document the morphological similarities, which Lima-de-Faria calls 'isomorphisms'[12], between organic and inorganic life forms. Lima-de-Faria annotates these images with his observations; for instance 'an insect resembles a leaf, the result is a physic-chemical isomorphism' (Lima-de-Faria, 1998:110). Following the visual observation of resemblance he offers further analysis[13], for example 'these similarities spring from identical atomic and molecular construction. Symmetry is a basic feature of plant organization as well as of animal organs and bodies' (Lima-de-Faria, 1998: 110) (Fig.13).

The images in *Evolution without Selection* are intrinsic to Lima-de-Faria's conceptualisation of 'evolution' as something fundamental to the entire material world. Lima-de-Faria discusses developments in particle physics, crystallography and molecular biology as part of his own radically different approach to biological evolution. This approach includes a presentation of biological form as a continuation of the inorganic matter of the physical world, the essence of which is the combination and superimposition of a limited number of initial forms and functions. Lima-de-Faria remarks that 'several ideas in this book can already be traced back to Pasteur, Goethe or Aristotle', and D'Arcy Thompson (as discussed later in chapter eight) is foremost amongst the text's introductory quotations: 'cell and tissue, shell and bone, leaf and flower, are so many portions of matter, and it is in obedience to the laws of physics that their particles have been moved, moulded and conformed' (D'Arcy Thompson, 1952). The solicitation and subsequent use of this quotation indicates Lima-de-Faria's interest in the relationship between Thompson's oeuvre and philosophical writing on modern physics. Through many examples of resemblance between the animal, mineral and vegetable, Lima-de-Faria addresses an absence in the neo-Darwinian approach:

Minerals are obviously excluded from any homology or analogy with plants or animals [...] moreover, between the plants and the animals no homologies are supposed to exist. Any resemblances between minerals, plants and animals are considered accidents or curiosities (1998: 24)[14].

11 Predominantly photographic at both macro and micro scale

12 This research does not claim to correlate resemblance to 'physic-chemical' relations.

13 Lima-de-Faria's analysis often have a slightly reductionist flavor which this research does not support.

14 Lima-de-Faria outlines one of the main reasons for this being due to the consideration of the gene as the determinant of all types of pattern whereas he proposes that resemblance is based on a physic-chemical ancestry.

Lima-de-Faria considers the limited forms that evolution works with through an extensive visual survey of forms, which reveals symmetries shared across the animal, mineral and vegetable. Images such as Fig.9, which documents bilateral symmetry in animal, mineral and vegetable species, have informed my own visual survey which builds on his research (Fig.10). Lima-de-Faria's work offers a critique of the modern paradigm of scientific classification (in the 1990s), through a line of questioning that integrates a visual element into the argument.

<u>Resemblance as a basis for classification</u>

Classifying organisms into non-overlapping kinds or species on the basis of morphological properties is thought to date back to Aristotle (Dupré, 1993: 54) and can be traced through works like *Phytognomica* and *Evolution without Selection*. To give a philosophical context for the development of my own contemporary alternative or 'extra-scientific' approach to classification, I draw on the work of the philosopher of biology John Dupré.

Dupré, in *The Disorder Of Things* (1993), argues for a pluralistic approach to biological classification. He offers a philosophical justification for developing many classificatory systems, saying: 'there are countless legitimate, objectively grounded ways of classifying objects in the world and these may cross classify one another in indefinitely complex ways'. He suggests ways of discovering alternative classificatory forms that can also be pluralistic, and argues that these may be 'real' so long as they are based on objective properties of the objects of study (Dupré, 1993: 17). This research centres upon specimens that have visible 'objective' resemblances to one another, but through an artistic practice which also allows the imagination to enter the process of representation. The biologist J.S.L. Gilmour (1906-1986) provided arguments that support Dupré's acknowledgement of plural relationships between species of objects and life:

> If we can once and for all lay the bogey of the existence of true relationship and realise that there are, not one, but many kinds of relationship – genealogical relationship, morphological relationship, cytological relationship, and so on – we shall release ourselves from the bondage of the absolute in taxonomy and gain enormously in flexibility and adaptability in taxonomic practice (Gilmour, 1951:401)

Other contemporaries of Dupré, such as Marc Ereshefsky, have focused on a critique of the current Linnaean scientific system of classification. The Linnaean system emerged in the18th century at a time when biological classification was a chaotic discipline marked by miscommunication and misunderstanding. It introduced clear and simple rules for constructing classifications, which became widely accepted by the end of the 18th century. In the chapter 'Species and the Linnaean Hierarchy' (1999) Ereshefsky describes how, in the last two hundred years, ideas of 'species' changed to acknowledge that species are products of evolution, subject to change and temporality. Ereshefsky believes that the Linnaean system is no longer practical for constructing classifications, and outlines eleven recommendations[15] for the post-Linnaean system in his book *The Poverty of the Linnaean Hierarchy* (2007). These include changes to names, hierarchies and modes of representation. Ereshefsky repudiates the hierarchy of categorical ranking in the Linnaean system and suggests the impossibility of defining the complexity of the natural world in twenty-four ranks. He says that 'biological theory has changed drastically in the last two hundred years. Perhaps it is time we changed the way we represent the organic world' (Ereshefsky, 1999: 302). Although Isomorphology is not presented with any ambition to replace the Linnaean system, my research and art practice is predicated on the contemporary evaluation of classificatory plurality.

Establishing a species concept as the basis for an alternative classification system

It is important to stress the need for classification systems that can accommodate and use divergent approaches to taxonomy. Philip Kitcher[16] and John Dupré have published writing on the importance of pluralism in taxonomy. My research and art practice follows this critical tradition by emphasising the polyvalence inherent to each Isomorphology drawing. In *The Disorder of Things,* Dupré describes Putnam's[17] theory of biological classification: 'once a paradigmatic exemplar has been identified, the kind is then defined as consisting of all those individuals that bear an appropriate "sameness relation" or resemblance to the exemplar'(Dupré 1993: 19). This species concept of the 'exemplar' can be applied when drawing the resemblance between two specimens which have hexagonal morphology; in such a case, the exemplar can be understood as the hexagonal form. Dupré writes 'the seeker of any categorical order must ascend to some higher level of abstraction' (1993: 20). This research considers any particular category, in this case a visible form or symmetry e.g. the hexagon, to belong to one

15 Ereshefsky describes one of which as the numerical systems proposed by Griffiths, Hull and Hennig which developed the original model by Sokal and Sneath and Sibley and Jardine (Wilson, 1999: 300).

16 Philip Stuart Kitcher (b.1947) is a British philosophy professor who specialises in the philosophy of science, the philosophy of biology, the philosophy of mathematics, the philosophy of literature, and, more recently, pragmatism.

17 Hilary Whitehall Putnam (b.1926) is an American philosopher, mathematician and computer scientist who has been a central figure in analytic philosophy since the 1960s, especially in philosophy of mind, philosophy of language, philosophy of mathematics and philosophy of science.

form species and display some 'sameness relation' or resemblance to other members of that species. It is then helpful to think of the hexagonal form as determining a species or category; animal, mineral, and vegetable species that show hexagonal form can be classified as examples or 'invariants' of that form species.[18]

The idea of an invariant in the form of a common structural plan or static 'schema' is a comparative methodological principle for finding a way through the multiplicity of forms (Tournefort, cited by Russell in Form and Function 1982:15). The 'unity of plan' argument advanced by Geoffroy which he extended from vertebrates to invertebrates based on homological relationships (Geoffroy, 1820) is linked to the Isomorphology argument and is discussed through a more detailed account in the next chapter.

This line of thinking supports an abstract and visual species concept of the type that I propose, a concept which is consistent with and supported by Philip Kitcher's proposal of a 'pluralistic realism' (1984: 308-333). Kitcher's writing provides for a 'realism' to encompass the insights of several divergent approaches to defining species which is in line with the 'integrative biology' approach suggested by Olivier Rieppel[19]. In his paper 'Species' (1984), Kitcher defends a concept of species as 'sets of organisms related to one another by complicated, biologically interesting relations. There are many such relations which could be used to delimit species taxa […] in short, the species category is heterogeneous' (Kitcher, 1984: 309). Like Ereshefsky, Kitcher invites different approaches to taxonomy, saying 'biology needs a number of different approaches to the division of organisms, a number of different sets of 'species'. Through the Isomorphology study, I have devised an alternative set of relations to challenge the established ways of classifying and marking the boundaries between the animal, vegetable and mineral, therefore advancing and building on Kitcher's suggestion of a heterogeneous species category through an artistic approach. My research and art practice builds on the tradition of a species concept based on morphological features, but provides a species concept which crosses the boundaries of the animal, mineral, and vegetable.

18 At the 'Labels, Catalogues and Architectures: The Art and Science of Modern Systematics' symposium (Schloss Herrenhausen, Hannover, Germany, June 24-27, 2015), the Philosopher and Physicist, Thomas Reydon asked if I arrived at the form species based on the experience of observing many individuals (comparable to the approach in Biology, or known as 'a posteriori') or if they were conceived in an 'a priori' way, independent of experience, as practised by mathematicians? In response to this question, I explained that the form species are arrived at through the experience of observing many museum and field specimens, then abstracting a general feature from many resembling specimens which I then dimensionally demoted to two dimensional form species, thus revealing an 'a posteriori' approach.

19 During Rieppel's 'Art and Science of Modern Systematics' conference presentation. Olivier is Rowe family curator of evolutionary biology at the field museum Chicago.

Here, species are not identified through a system of names and numbers or through the syntax of language, but instead through a visual system of abstract forms and symmetries. The Isomorphology drawings (which I will now introduce) give physical body to the concept of Taxonomic Pluralism.

An alternative approach to classification: Isomorphology

Dupré's concepts of classificatory pluralism and promiscuous realism establish that there are many properties that classifications can be based on and imply that no single system of classification is unquestionably most useful. He also says 'Classifications, must, in some sense, be discovered rather than merely invented' (Dupré, 1993: 17). This is reflected through the many possible priorities set by the various approaches of different epochs. As discussed earlier in this chapter, through my own extended drawing experience, I have realised that behind observed resemblances are various 'types' or 'properties' of form and symmetry. This began as an intuitive group of form species (Fig.11), that provides a basis for 'Isomorphology'[20] – a neologism I have coined for a practice I define as 'the study of the shared forms and symmetries of animal, mineral and vegetable species through drawing practice' (Anderson, 2012).

'Isomorphology' Etymology, from Greek: 'Isos' | 'Same/Equal', 'Morphe'' | 'Form', 'Logos' | 'Study'.

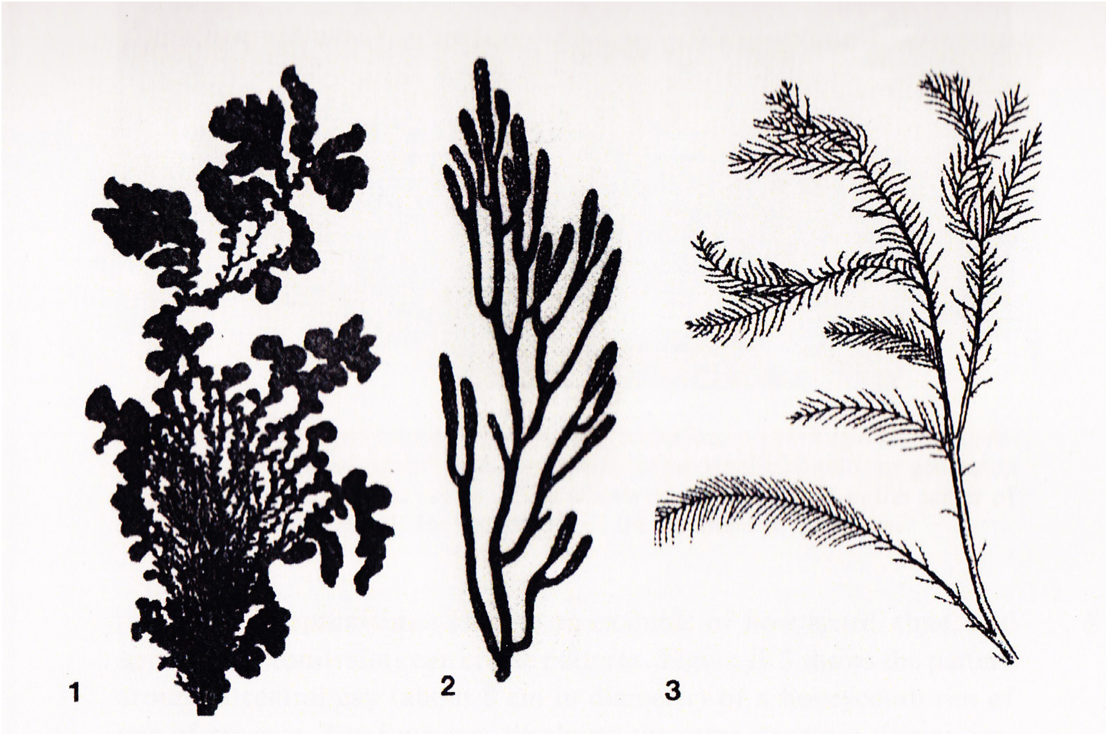
The shared forms and symmetries of Isomorphology (Fig.12) can be viewed through the lens of Dupré's 'species' concept as 'a class of objects defined by a common possession of some theoretically important property' (Dupré, 1993: 22)[21]. Isomorphology proposes visual 'form species' which set priority on form and symmetry[22]. These two properties turn standard classification on its head to show that there are alternative ways to classify natural life across kingdoms. As such, Isomorphology is in line with Dupré's pluralistic view.

The form species of Isomorphology (Fig.13) draw connections between species that, according to the Linnaean system, are currently unrelated. However, Isomorphology appropriates a base from the Linnaean system and simultaneously rejects and depends on both the Linnaean system and the museum system, which although imperfect,

20 The term species is reserved for the exemplars of form and symmetry which underlie resemblance

21 Also relates to Aristotle's definition of species as a logical category and Otto Neurath Isotype's.

22 While form and symmetry are not the currently central concepts for classifying life, they are not bizarre and form has been central in the past. In fact form and symmetry are fairly central for Linnaeus



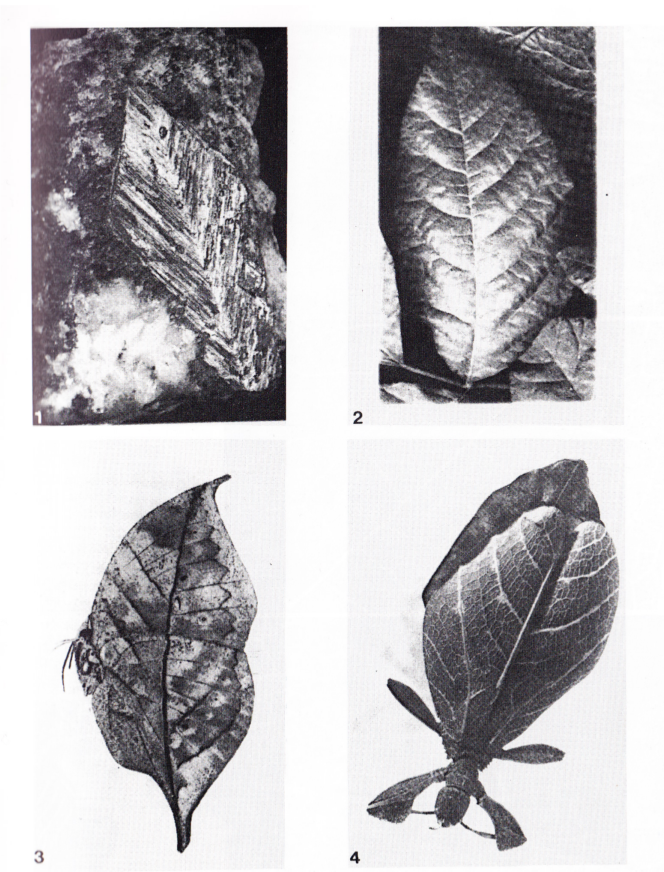


Figure 14.
LIMA-DE-FARIA, (Lima-de-Faria, 1998, Fig.9.8). Branching forms (animal, mineral, vegetable). Collage of photograph and drawing by unnamed artist/author. From *Evolution without Selection* pp.95.

Figure 15.
LIMA-DE-FARIA, (Lima-de-Faria, 1998, Fig.3.8). Leaf Pattern. Collage of photograph and drawing by unnamed artist/author. From *Evolution without Selection* pp.27.

provide an organised natural world. Without taking advantage of such prior systems of collection and classification such a disorder would reign that any attempt at navigation would be impossible. Isomorphology is therefore an innovative and complementary approach, and one that intends to blur normative animal, vegetable, and mineral boundaries.

The Isomorphology study – a research project toward creating a series of artworks, which draw together specimens of each form species – began by listing[23] a two dimensional 'bauplan'[24] for each of the form species and visual lists of examples (Fig.12), informed by the images in *Evolution without Selection* and *Phytognomica.* Using these sources and my own observational drawings as a starting point, I compiled a list of specimens held within the NHM collections which relate to the form species of Isomorphology (Fig.10). This provided enough information to approach the NHM for permission to access its research collections. Of particular importance were the images in Evolution without Selection that pertain to Isomorphology's form species, for example: hexagonal patterns in body formation of mineral, animal (vertebrate and invertebrate), plant and five-fold symmetry (Fig.13), ramified patterns in the body formation of molecules, protozoa vertebrate and invertebrate bodies (Fig.14) and leaf patterns (bilateral symmetry) in animal, mineral and vegetable species (Fig.15).

These initial lists, which collected many more species' names than could be drawn, operated as a flexible way to navigate the morphology of animal, mineral, and vegetable specimens within collections. This navigation aimed to select specimens to draw based on the criteria of resemblance to the form species of Isomorphology. The next stage utilised these lists as a guide to 'screen' hundreds of specimens with curators in the zoology, mineralogy and botany collections at the NHM. As this work demanded the observation of specimens, it required a process of attaining permission to observe and to draw, which I coordinated on each occasion. Access to many specimens, especially valuable minerals in the NHM collections, is limited and the Isomorphology artworks offer an alternative mode of display and means of making these collections visible.

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23 I compiled a series of lists of species, which I then presented to a number of scientists and to artist William Latham to find out if the set made sense from their perspective.

24 From Woodger's concept of bauplan in *Form and Function*, (Russell, 1982: 16)

Figure 16.a.
ANDERSON, Gemma, 2012. 'Isomorphology: Bilateral Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.b.
ANDERSON, Gemma, 2013. 'Isomorphology: Three Fold Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.c.
ANDERSON, Gemma, 2012. 'Isomorphology: Four Fold Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.d.
ANDERSON, Gemma, 2013. 'Isomorphology: Five Fold Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.e.
ANDERSON, Gemma, 2013. 'Isomorphology: Six Fold Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

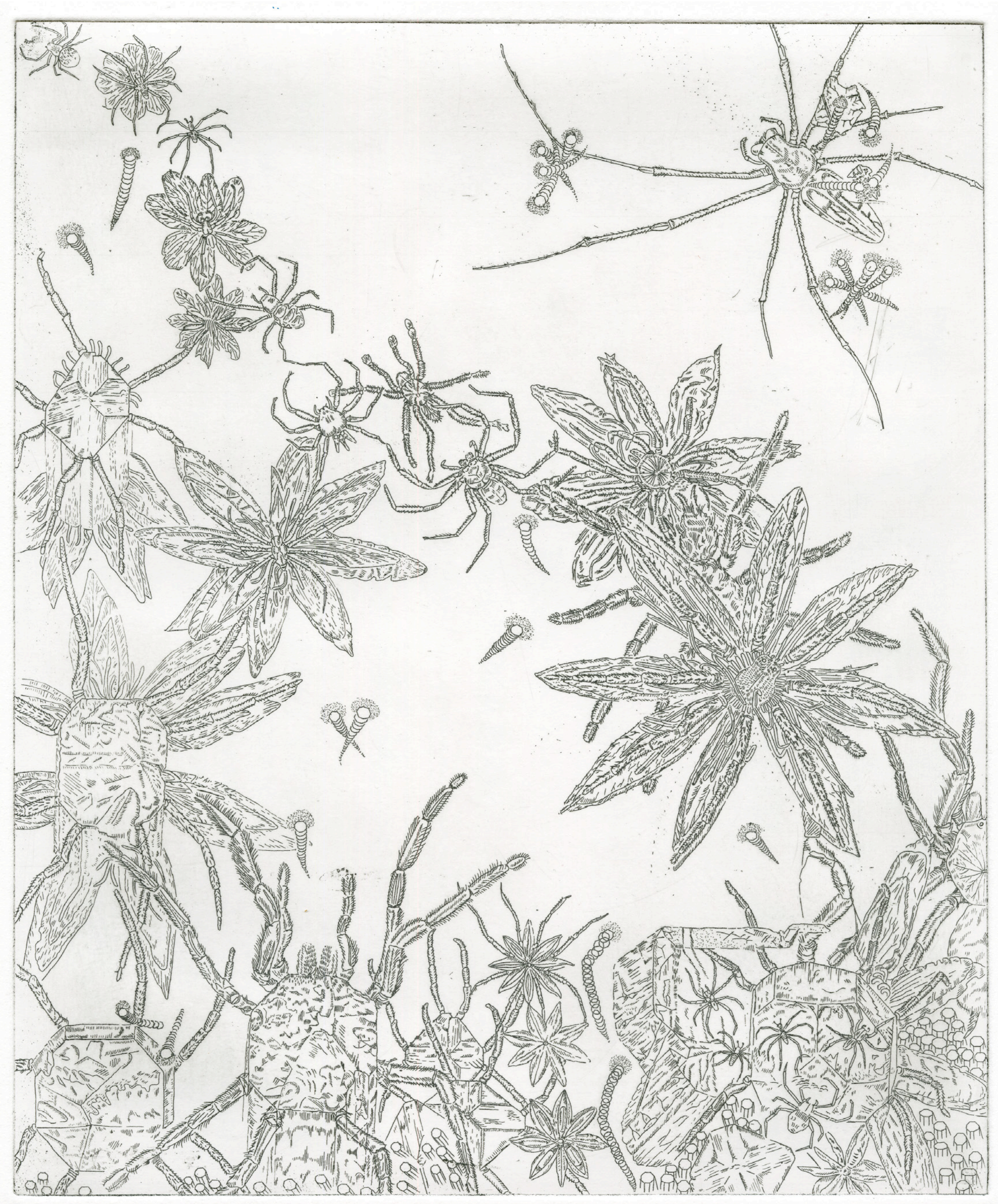

Figure 16.f.
ANDERSON, Gemma, 2013. 'Isomorphology: Eight Fold Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

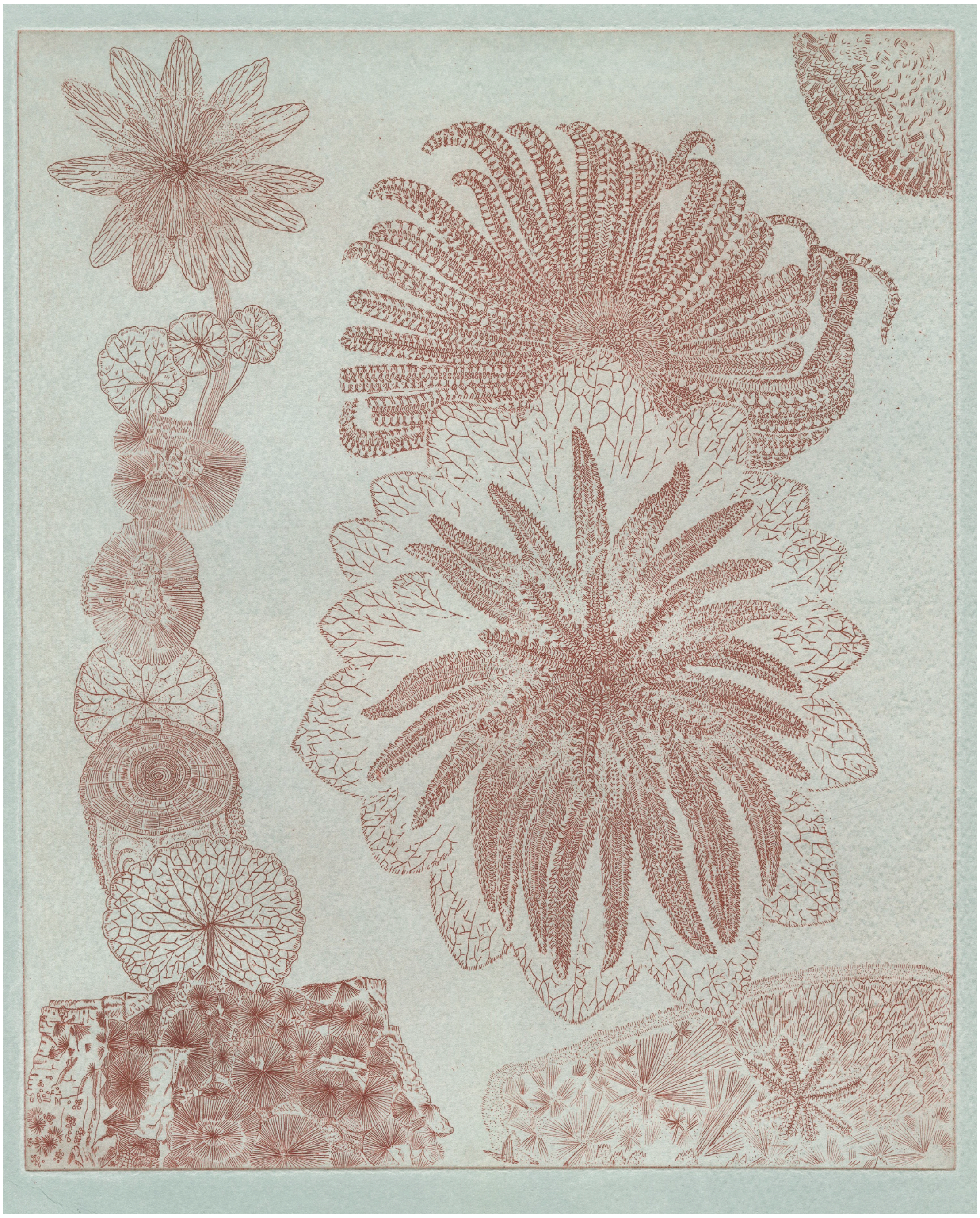

Figure 16.g.
ANDERSON, Gemma, 2014. 'Isomorphology: Radial Symmetry: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.h.
ANDERSON, Gemma, 2014. 'Isomorphology: Spherical Form: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.i.
ANDERSON, Gemma, 2014. 'Isomorphology: Phallus Form: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.j.
ANDERSON, Gemma, 2014. 'Isomorphology: Branching Form: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.k.
ANDERSON, Gemma, 2013. 'Isomorphology: Spiral Form: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Figure 16.l.
ANDERSON, Gemma, 2013. 'Isomorphology: Hyperbolic Form: Animal, Mineral, Vegetable', (Drawn from The Natural History Museum collection). Copper etching and Japanese inks on paper. (© Anderson)

Reflection on the difference between biological taxonomy and Isomorphology

The biological 'type' method (see page 149) assigns the label of a 'type' to a particular individual which then becomes the reference point for that species. In biological science, the type must be given a name which follows the guidelines established in the 1930s in Cambridge (as a compromise between America and Europe to find a common language). The type is designated 'a posteriori' after empirical research and observation of many individuals within this species (or whatever is available). My approach to classification does not employ the type method - I have not selected a specimen as an example of the spiral form species and, most importantly, I do not give a name to any specimen. Currently, type can be diagnosed by a written description only. In the paper 'Linnaeus did not write descriptions, so why do we?' presented by Suzanne Renner (Director of Munich University Herbarium) at 'The Art and Science of Modern Systematics' symposium, (Hannover 2015) Renner advises the diagnosis of type specimens and related species through an image and DNA analysis. Renner's recommendation is alternative to the current culture in contemporary taxonomic practice (at the NHM for example) where written description and number are most common in species diagnosis. Renner's recommendation would mean a diagnosis of type without conventional language, which would be extremely unconventional for biological taxonomy. Renner's view supports my argument for drawing as epistemology for morphology and, if this recommendation for species diagnostics was implemented in the scientific community, more value would be assigned to drawing, its practices and the knowledge that it generates.

Isomorphology as an extra-scientific way of knowing

Isomorphology is intended to produce findings that will create a dialogue with conventional modes of scientific knowing. Classifying, as understood by Dupré as 'imposing conceptual order on diverse phenomena' (Dupré, 1999: Chapter 3), aligns with the aims of Isomorphology. Isomorphology parallels the scientific practice of taxonomy as a comparative, drawing-based method of enquiry into the shared forms of animal, mineral, and vegetable morphologies to find similarities, not differences. Unlike scientific taxonomy, Isomorphology is not seeking to establish a stabilised order. Here, these are two different 'orders' at stake: the stability of the taxonomic account and the natural order itself. The first is constructed and the second is a kind of chaos that invites attempts at classification. Isomorphology provides one of these many ways to navigate morphological diversity. As there is no commitment to any unifactoral[25] evaluation of

25 Involving, dependent on or controlled by a single gene

phenomena, Isomorphology is not objectively reductionist in approach. These similarities and differences make Isomorphology complementary to scientific classification. Isomorphology addresses relationships that are potentially undervalued by the scientific classification of animal, vegetable, and mineral morphologies and suggests that there are many possible ways to explore and organise the natural world.

Isomorphology therefore aligns with Dupré's outline of classificatory pluralism that rejects the existence of any uniquely correct scheme of classification. It too denies essentialism. As a dynamic rather than static approach to classification, Isomorphology, which uses lists in the early stages of the process, does not put things into lists in its output, but rather draws dynamic relations through a flexible and plastic artistic process 'pursuing an endless zigzag course from resemblance to what resembles it' (Foucault, 1990: 33). A contribution of my approach has been the creation of a flexible set of form species, which provide the basis for classification. Isomorphology is not a static system, it is always an evolving practice and a process. Isomorphology is a concept that depends on the purpose for which it is intended: to navigate, to observe, to draw and to know the natural world. It is therefore a blending of scientific and artistic experimentation which brings with it new modes of seeing and classifying the natural world. By placing the making of observational drawings at the foundation of this artistic experimentation, Isomorphology demonstrates drawing's continued viability as an epistemic process and as a way of producing knowledge.

The Isomorphology image-making process; similarities and differences with Lima-de-Faria's image making process

Evolution without Selection makes its by-category taxonomies visible through the presentation of related but separate images. Isomorphology offers a visual representation of the shared forms and symmetries of animal, mineral, and vegetable specimens, as connected through drawing which consistently includes specimens from all three kingdoms in each image, which Lima-de-Faria does not do. Isomorphology uses the specific approach of drawing to then select morphological features and draw these relations together into one interconnected image. Lima-de-Faria includes photographic examples of resemblances between the animal, mineral, and vegetable, but often compares the animal and vegetable or the vegetable and mineral rather than showing examples of resemblances that cross all three kingdoms. Unlike Lima-de-Faria, who compares specimens at macro and micro levels, Isomorphology consistently gives attention to specimens at a macro scale.

As discussed in chapter two, handling specimens in person allows for the selection of perspective from which any subsequent morphological drawing is made, whereas found images offer only a fixed perspective[26]. Isomorphology was developed through drawing specimens found in museum collections, and has inevitably led to observing forms and species that have not been imaged in scientific texts. The selection of perspective is intended to elucidate the purposiveness of bias and discovery in this artistic taxonomy. These differences can be understood through comparing this image of Lima-de-Faria's 'leaf pattern' (Fig.15), and the Isomorphology etching of a leaf image (Fig.16). As the comparison of these images reveals, Isomorphology is complementary to Lima-de-Faria's approach[27].

Reflections on the Isomorphology drawing process

The following text reveals the intricacies of the Isomorphology drawing process at the NHM. Further to this, specific information about how this process began is located in Appendix A.1.

1. Observation

Permission to draw and handle museum specimens enables close visual and haptic observation, revealing unexpected comparisons of form as such specimens were selected from collections on the basis of their morphological features and on resemblance to the form species, e.g. hexagonal form. The specimens were then laid out in my lab space in the Sackler Imaging Centre in the Darwin Centre at the NHM. The specimens were then drawn directly onto the copper plate. This is an unusual process that commits each mark to the plate and allows only one chance at making the image[28]. As discussed in chapter two, observational drawing involves hand-eye coordination,

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26 The Isomorphology study, focused on macro specimens mainly due to restricted access to microscopic technology (too expensive and only available through CSM and NHM).

27 Lima-de-Faria's process of image construction involved the following stages:
-Screening over 40,000 figures (micro and macro) in treatises and monographs of biochemistry, virology, mineralogy, embryology, cell biology, palaeontology, botany, zoology and other disciplines.
- Selecting over 1,000 images that were considered of interest and were photocopied, a literature reference was attached to each one.
- Sorting/classifying: the photocopies were then sorted out according to resemblance of both form and function irrespective of the organism or mineral group to which they belonged.
- A second and third screening was carried out to assemble the most relevant resemblances.
- Every original figure was then photographed directly from the original book and the prints were put together into plates.

28 I arrived at this way of working after years of drawing practice in which re-working a drawing has not been a priority because my drawings are motivated by question asking and generate further questions in the creative process. Therefore I am more interested in the process rather than product of drawing.

analysis, delineation, abstraction, improvisation, collage and deep concentration. This is enhanced through handling the specimen, which allows for the rotation of the object and the selection of a perspective to draw from. Perception of the object is a process of transition from experience to judgment, insight to application. Concentrated observation within the act of drawing creates new perceptual knowledge, activating the process of comparison and selection of salient features. Each form observed joins a 'bank' of knowledge in the observer's mind and each new drawing experience triggers a different formal memory 'stored' in this 'bank'. New drawings add value to drawings previously made, and vice versa.

2. Perspective

As there are many possible answers to the question 'what are the forms and symmetries of this animal, plant, or mineral?', it is consequence of choosing one perspective to draw from the automatic exclusion of a thousand others. With any given organism there are many possibilities for observing the forms and symmetries of Isomorphology, depending on focus. First comes observation of forms that are more obvious, for instance branching forms, and then of more subtle or complex forms, like the spiral arrangement of the inner flower. The chosen perspective opens up new possibilities for abstraction, for example: a cross section of the stem can be viewed as a multi-sided prism or rocks abstracted to isosceles triangles, each individual a variation on a theme.

3. Decision-making and classification

Decision-making happens consciously and unconsciously. Decisions are made first in the field or museum, these are decisions based on observed form and symmetry, and then later in the studio or lab. When drawing I make decisions about perspective, rotation, whether to draw parts of or the whole specimen, to zoom in or zoom out in order to select salient morphological features which relate to the form species of Isomorphology. I also make decisions of composition, about where to begin the drawing, how to build its form and where to end, and these are largely intuitive decisions based on my experience as an artist.

Specimens are selected based on their visible relation to the Isomorphology form species and then classified in the lab space before drawing, during which some are de-selected[29]. Then there is a further selection/classification when choosing what to draw, which parts to draw. Each collection and order is motivated by an enquiry into form

29 Specimens may be deselected because their morphology is not as visible as others.

and symmetry, which directs and determines the collection whilst allowing for chance operations to occur and be subsequently included.

4. Translation between two and three dimensions

The Isomorphology symbols (Fig.12) are two-dimensional symbols that have been abstracted from the observation of three-dimensional specimens. In observations in the field and of museum specimens, this dynamic is reversed and the two-dimensional symbols are projected on to three-dimensional objects: plant, mineral, or animal. The process of applying an abstraction to the reality of the observed specimen depends on the motivation and training of the individual observer. Observing in the field is both an act of interpretation and of translation, and so it requires a conceptual flexibility of working between the 2-D and the 3-D. I use 2-dimensional forms and symmetries as a guide to begin drawing and then furnish this plan with idiosyncratic details of the individual object. The observer's mind, which the project inclines towards symmetry, completes the imperfections of the reality of a specimen by projecting the abstract onto the observed to complete the picture.

During the process of drawing it becomes apparent that individual plants are sites of many of the forms and symmetries of Isomorphology; each body begins to reveal itself as yet another composite: a landscape of form[30]. Plants can have isomorphic relationships in their internal workings and composition, therefore individual plants are sites of composition and some parts of the plant seem more important because they gesture out toward resemblance with other plants, and this is analogous to the role of the artist as classifier. As Berger says:

For the artist drawing is a discovery, it is the actual act of drawing that forces the artist to look at the object in front of them, to dissect it in their mind's eye and put it back together again (Berger, 2005:3).

With a collection of specimens it is helpful to then identify two or more specimens (and possible to mix up specimens from field or museum) that share a form or resemble each other. For example, when drawing two branching forms it is helpful to first imagine how to draw this relationship. This requires an act of visualisation and to then make this visualisation visible to others through the act and object of drawing.

30 It quickly becomes apparent that each plant/animal mineral form we look at is a composite of more than one of the forms of Isomorphology. Each 'individual' becomes a community of form species.

5. Abstraction

Drawing enables the development of abstract thinking and allows previously unperceived relations between objects to be discovered, it facilitates the unlearning of conventions of classification. The majority of knowledge of the object and its conventional context and name are forgotten; what is left is an involvement in the comparison and selection of form. The focus shifts from drawing the whole body to drawing a series of component parts. Drawing in this way leads to modes of knowledge that enable a departure from observation and a liberation of form toward previously unthought-of creative possibilities.

6. Improvisation

Drawing the natural world as a chain of resemblances, merging object bodies into one another and creating a newly classified order all require artistic improvisation. Through improvisation the morphology of different bodies can be freed from the artist's agency and suggest art within the parameters of the drawing space. Improvising through drawing is a kind of 'sampling' or re-mixing of natural form - recombining like a strand of DNA creating a new order for the parts. This improvisation runs throughout the creation of each Isomorphology etching, which is drawn directly onto the copper plate (as discussed in chapter two). This immediate way of drawing, in which each line is a permanent, non-erasable commitment is surprising, challenging, and uncomfortable. The drawing is often driven by solving the initial feeling of 'this is not working', which needs to be overcome, and requires improvisation to continue. The drawing process can be compared to building: each drawing, which selects morphological features from a specimen, either attaches to a drawing made earlier or generates a new drawing site for building on the plate. This process does not follow a linear order but unfolds in response to the drawing as it arises.

In my own experience, when drawing, the memory embeds the observed forms. The practice of drawing, which requires lengthy observation before commencement, enables the drawer to recognise the form species of Isomorphology and to improvise with the form, by partially or completely not looking at the specimen. The drawing process shifts from direct observation to improvising. Isomorphology uses functions of memory to liberate the drawing process from observation's dominance. These stages reflect the process[31] through which I created the 12 Isomorphology etchings[32] (Fig.16).

31 For details of image-making process, see Appendix A.2
32 Copper plates are then etched and printed in the printmaking workshop

Figure 18.a.

Figure 18.b.

Figure 19.a.

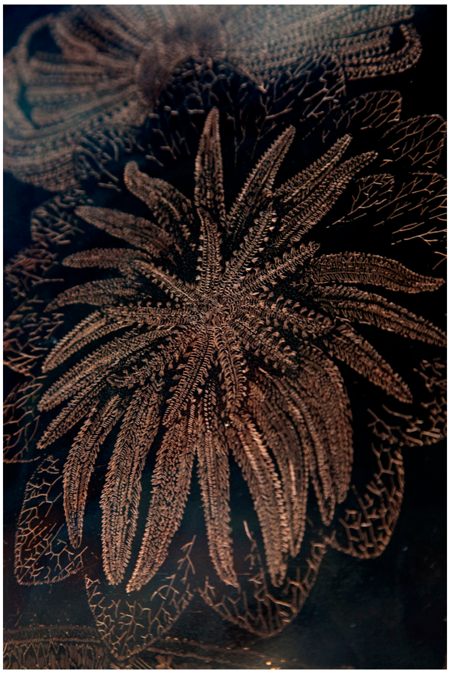


Figure 19.b.

Figure 18.a.
Natural History Museum Photographer, 2013. View of designated bench space for Isomorphology study in the Sackler Lab, Darwin Centre, The Natural History Museum. Photograph. (© Anderson)
Figure 18.b.
Natural History Museum Photographer, 2013. View of Anderson drawing at designated bench space for Isomorphology study in the Sackler Lab, Darwin Centre, The Natural History Museum. Photograph. (© Anderson)
Figure 19.a.
ANDERSON, Gemma, 2012. Copper etching plate in progress. Photograph. (© Anderson)
Figure 19.b.
ANDERSON, Gemma, 2012. Copper etching plate in progress, close up. Photograph. (© Anderson)

Figure 20.

Figure 21.

Figure 20.
Grant Museum, University College London, 2013. Isomorphology workshop at the Grant Museum. Photograph. (© Anderson)
Figure 21.
ANDERSON, Gemma, 2013. Isomorphology form temporally installed amongst Grant Museum Zoological collections. Photograph. (© Anderson)

Sharing the practice of Isomorphology with others

The educational motivation of Isomorphology has existed since developing the original idea in July 2012, as reflected in the following extract from my journal[33]:

> 'After marking the 1forms and symmetries of Isomorphology, I went for a walk around woodlands to observe the forms and symmetries in the plant life. I began to see the bilateral leaves, branches, bilateral leaves on branches, and began to ponder the possible combinations of the form and symmetries (draw). It was such a pleasure to feel that at last I am deducing something meaningful (other than beauty and wonder) from my observations and I am happy to have a concept that is joyfully developed through the combination of observation and intellect, empirical and abstract at once. The possibilities of how Isomorphology may open my understanding and approach to artwork and ideas is very exciting, especially the possibility of proposing 'Isomorphology' as an educational model, through which a student can learn aspects of mathematics, botany, zoology and mineralogy simultaneously and a concept they can develop for themselves in their own garden!' (Anderson, 2012).

I promote Isomorphology as an approach that requires drawing practice and tuning the eye into this way of seeing the world. To explore the possibilities of sharing this knowledge with others,

33 17/07/12, 8pm, titled 'Reflections on Isomorphology'

I have organised a series of workshops, which themselves contributed to my awareness of Isomorphology as a way of knowing. The first workshop was held at Tresco Abbey Gardens on the Isles of Scilly in 2012 and the last at the Cornwall Morphology and Drawing Centre in 2015, with a wide variety of locations and variations on the theme, ranging from the Natural History Museum to the Eden Project. I have summarised the practices of each individual workshop, which varied in context[34] and audience into a general Isomorphology method. This method presently stands as a workshop form for Isomorphology.

<u>Workshop Method</u>

As discussed in the introduction, the 'educational turn', considers artwork as an educational medium. I have chosen to develop the Isomorphology method into the form of a workshop, which aligns with the use of pedagogical models such as talks, symposia and workshops, which were historically used to support art practice, as the artistic practice itself. This form reflects the educational motivations of this research and interest in sharing artistic *process* rather than *product.* The workshop provides a vital opportunity for presenting and discussing the Isomorphology method, which develops a way of seeing and understanding the morphology of animal, vegetable and mineral through an open dialogue between participants, myself and occasionally a collaborating scientist.

First, I will outline the Isomorphology method which became clear through my own practice as communicated through the workshop practice.

1. Survey of form with Isomorphology form species as a navigation tool (participants are given 2-D forms as handout).
2. Apply 2-D forms to 3-D realities through observing field and museum specimens. This stage aims to begin to tune the observation to see the forms of Isomorphology and to apply the abstract two-dimensional symbols to the three-dimensional observed reality.
3. Raise questions for study, including 'What are the shared forms and symmetries of Animal, Mineral and Vegetable species?'. Reflect on and relate the motivations of those in science and art using drawing as an epistemological tool.

34 This process either sources specimens in the field (Loe Bar, Tresco, Eden) or organises loans from a variety of museum collections: Exeter University Zoology Collection, Grant Museum, Camborned School of Mines. In certain workshops, specimens from both the field and museum are combined.

4. Select specimens based on their relation to Isomorphology form species, and then gather in the work space[35] so an initial 'classification' and selection of specimens will be drawn.
5. Before drawing, spend time handling and observing specimens to make informed choices about perspective.
6. Visualise how resemblances between specimens could exchange to suggest art.
7. Start the observational drawing, which involves zooming in and out and starting to abstract the form species from the specimen.
8. Draw resemblances: placing resembling features alongside one another or in place of one another. Using resemblance to join/exchange morphologies through drawing.
9. Draw form without looking and begin to improvise, based on an abstraction of observed form and what has been learnt so far. This moves from observation and leads to abstraction and improvisation.
10. Draw a body or landscape of resemblance.

Workshops have become a way to reflect on my own method through the observation of others. As discussed earlier in chapter two and later in chapter nine, workshops are central to the evaluation of the epistemological value of drawing. In the workshop, it is important to consider the epistemological value of drawing as both process and object. Workshops are not only about sharing the Isomorphology practice but also about drawing and its epistemological value. I considered the drawing practices developed in this research to be valuable if they prove transferable between my own practice and an art, science or general audience.

35 This may be the museum, the field or the studio

Communicating Isomorphology

The communication of Isomorphology has been diverse[36], including two public exhibitions[37], an installation[38], three publications, four workshops and three public events, and one for the staff at the Natural History Museum[39]. The purpose of these activities is summarised here with reflection on what each contributed to this research project.

As a series of drawing workshops, Isomorphology has functioned as a transferable drawing method and a tool for navigating both the museum and the field. Workshops have been held at the museums: Natural History Museum, London, The Eden Project, Cornwall, The Grant Museum, London, Cornwall Morphology and Drawing Centre (see page 287), Cornwall and Tresco Abbey Gardens, Isles of Scilly. Workshops have also been held in the field locations: Loe Bar, Cornwall and St Ives, Cornwall (Fig, 20-28). An archive of workshops and reflections can be found in Appendix A.4. To merge the museum and field experiences in a single workshop, I organised a loan of zoological museum specimens from Exeter University for the St Ives sessions.

Figure 22.

Figure 23.

Figure 22.
ANDERSON, Gemma, 2014. Isomorphology workshop at the Drawing Room during 'Drawing Making: Making Drawing'. Photograph. (© Anderson)
Figure 23.
ANDERSON, Gemma, 2014. Isomorphology workshop at the Natural History Museum. Photograph. (© Anderson)

36 See Appendix A for more details
37 The exhibition 'Isomorphology', London (2013) and 'Riddles of Form' Berlin (2014), see appendix B.6
38 A Life Sciences Seminar, NHM, March 2013
39 These include: Nature live, NHM, Science Uncovered, NHM, TEDX and a Life Sciences lecture, NHM

Figure 24.

Figure 25.

Figure 26.

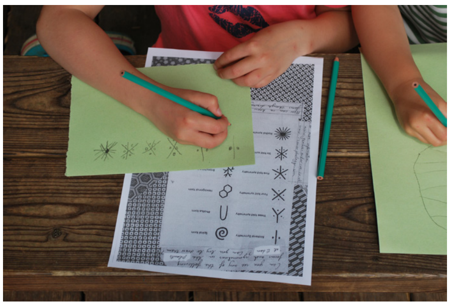


Figure 27.

Figure 28.

Figure 24.
ANDERSON, Gary, 2013. Isomorphology themed Nature Live at the Natural History Museum. Photograph. (© Anderson)
Figure 25.
BROAD, Gavin, 2013. Isomorphology themed Science Uncovered installation at the Natural History Museum. Photograph. (© Anderson)
Figure 26.
ANDERSON, Gemma, 2015. Isomorphology workshop at the Eden Project. Photograph. (© Anderson)
Figure 27.
ANDERSON, Gemma, 2015. Child drawing Isomorphology forms and symmetries during workshop at the Eden Project. Photograph. (© Anderson)
Figure 28.
ANDERSON, Gemma, 2015. Isomorphology workshop at the Eden Project. Photograph. (© Anderson)

I selected the following feedback about the Isomorphology workshop from a participant who offered reflections on the value of the workshop based on her background as an art teacher and as an artist. She says:

> Apart from the obvious benefit of approaching the natural world from the perspectives of an artist and a scientist, the activities included all the elements of a successful and meaningful art class: Structure in the form of clear guidelines for each stage of drawing.
>
> Learning through drawing becomes a game of discovery.
>
> You have succeeded in engaging imaginations, which have been enriched by carefully observed drawing. It is impossible to fail because something is created that has never before existed. I would love to use these drawing activities with my students.
>
> As an artist, on reflection this was one of the best courses I have ever taken.

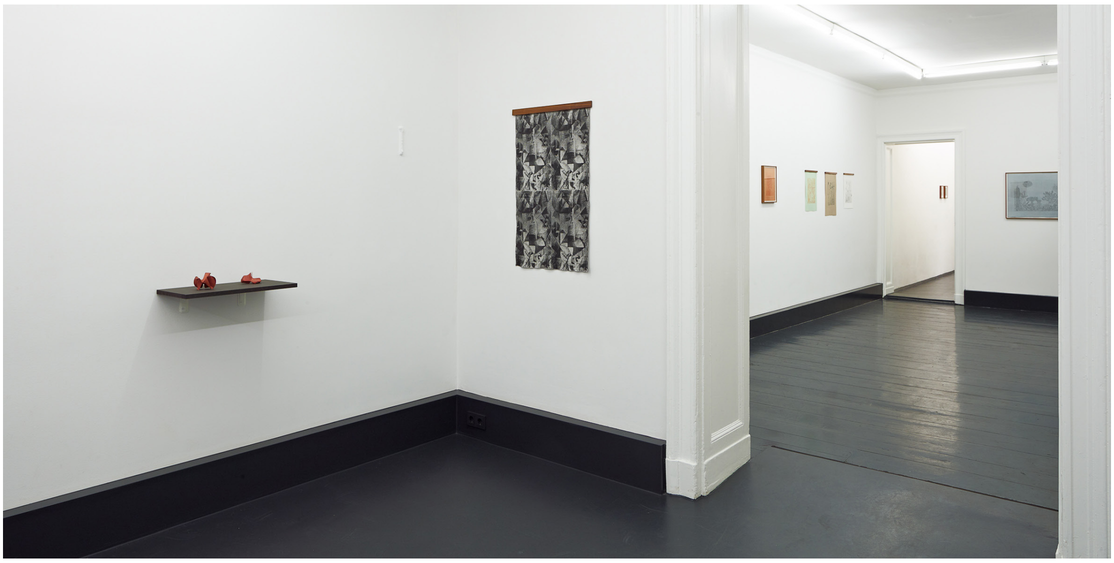


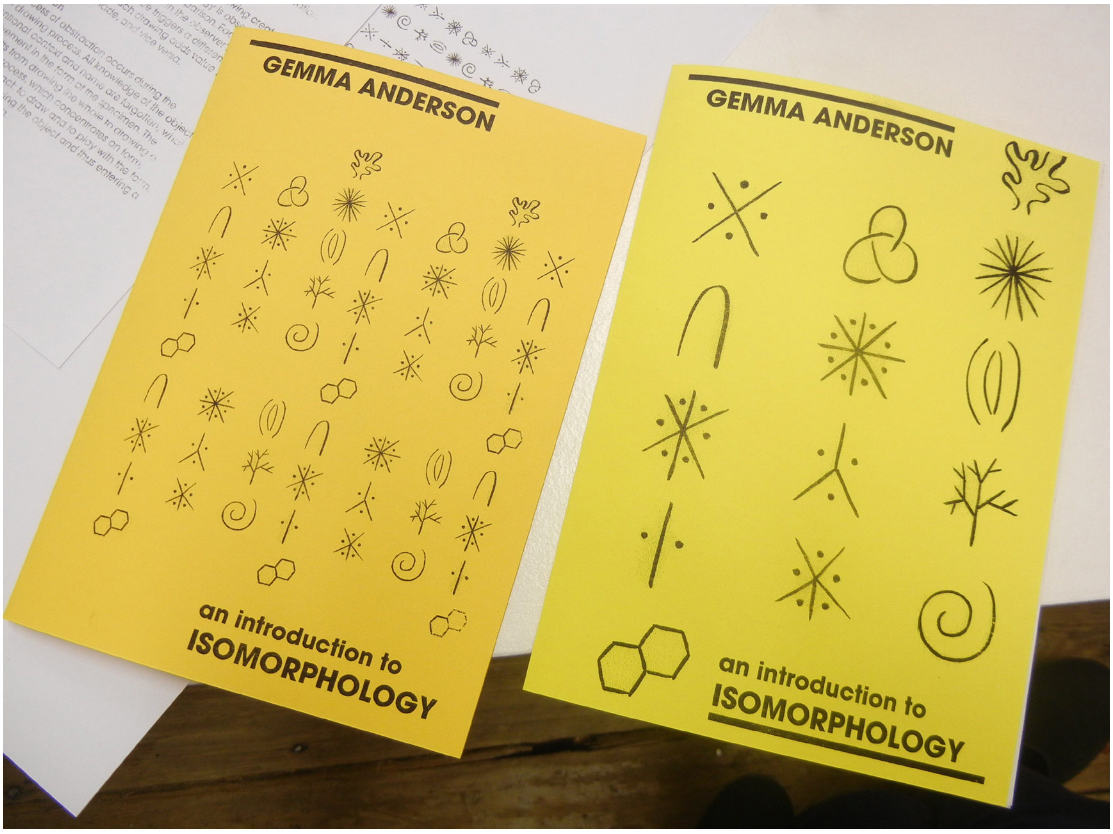
Figure 29.
ANDERSON, Gemma, 2014. Installation view of Isomorphology. Exhibition at Thore Krietmeyer Gallery. Photograph. (© Anderson)

Figure 30.
ANDERSON, Gemma, 2014. Installation view of Isomorphology. Exhibition at Eb and Flow Gallery. Photograph. (© Anderson)

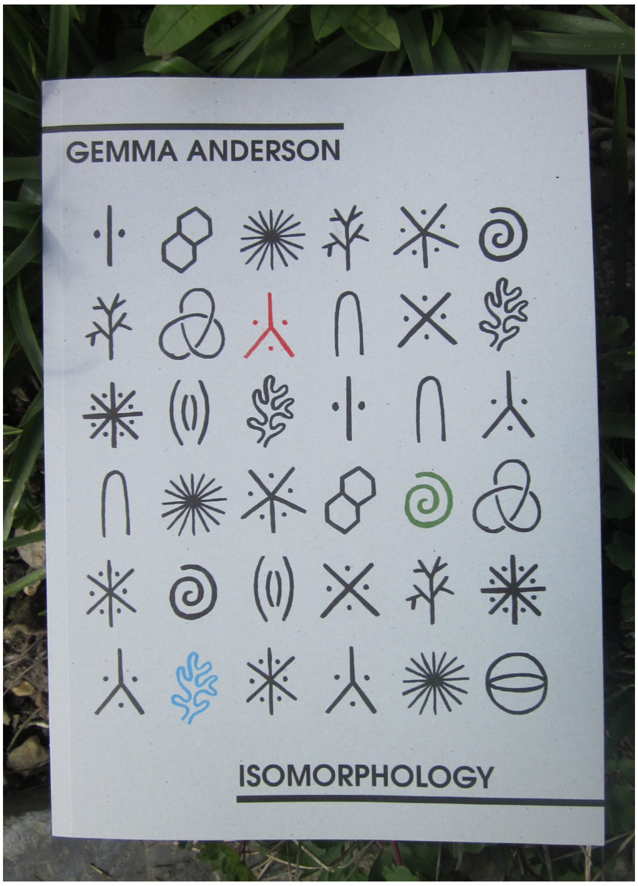
> Nature informs and drives my own work. I spend time drawing insect, plant and mineral specimens and use these observations as a basis for inventing new forms. However sometimes I feel that the symbols and marks I make are becoming "tired" and the outcome too predictable. Your class was fabulous, finally something original. I am able to use the forms of Isomorphology to inject some new life into my work.

These reflections are backed up by another participant, who has a history of working in design, who says:

> The Isomorphology workshops helped to expand my artist's mind and to explore different ways to interpret the natural forms. I like all the scientific studies behind how she came up with the Isomorphology concept and developed the alternative and visual approach to classification of the natural forms. I learnt all natural form can be view in the Isomorphic classification format and hope to bring this into other aspects of my art work (Jewellery designer).

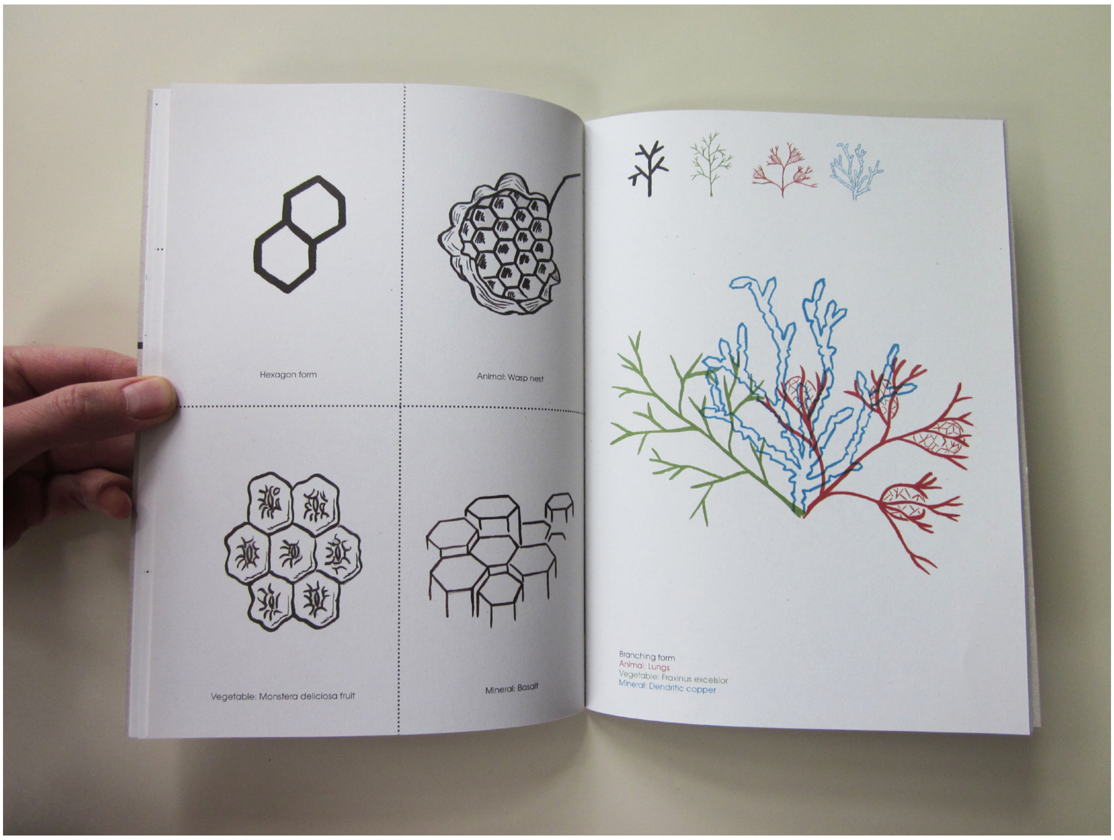


31.a.

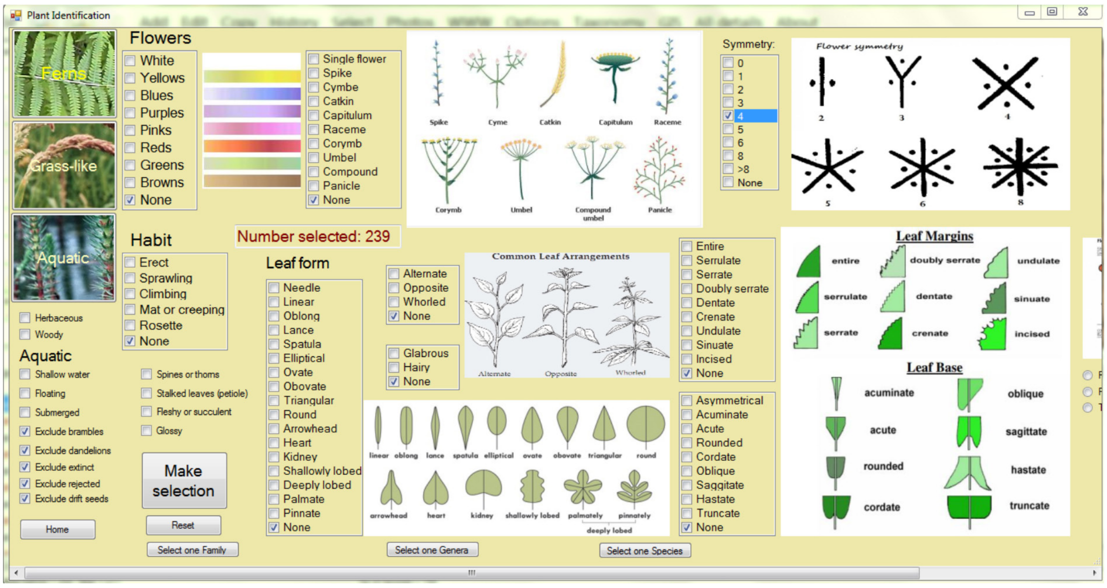


31.b.

Figure 31.a
ANDERSON, Gemma, 2013. Isomorphology Publication test covers (ref?). Photograph. (© Anderson)
Figure 31.b. ANDERSON, Gemma, 2015. Isomorphology Publication. Photograph. (© Anderson)
Figure 31.c. ANDERSON, Gemma, 2015. Isomorphology Publication, inside pages (ref?). Photograph. (© Anderson)
Figure 32
ANDERSON, Gemma, 2015. Isomorphology integrated into ERICA botanical recording software (see appendix for more details). Photograph. (© Anderson)


Hexagon form
Animal: Wasp nest
Vegetable: Monstera deliciosa fruit
Mineral: Basalt
Branching form
Animal: Lungs
Vegetable: Fraxinus excelsior
Mineral: Dendritic copper

31.c.


Plant Identification
Ferns
Grass-like
Aquatic
Flowers
White
Yellows
Blues
Purples
Pinks
Reds
Greens
Browns
None
Single flower
Spike
Cymbe
Catkin
Capitulum
Raceme
Corymb
Umbel
Compound
Panicle
None
Spike
Cyme
Catkin
Capitulum
Raceme
Corymb
Umbel
Compound umbel
Panicle
Symmetry:
0
1
2
3
4
5
6
8
>8
None
Flower symmetry
Habit
Erect
Sprawling
Climbing
Mat or creeping
Rosette
None
Number selected: 239
Leaf form
Needle
Linear
Oblong
Lance
Spatula
Elliptical
Ovate
Obovate
Triangular
Round
Arrowhead
Heart
Kidney
Shallowly lobed
Deeply lobed
Palmate
Pinnate
None
Alternate
Opposite
Whorled
None
Common Leaf Arrangements
Alternate
Opposite
Whorled
Glabrous
Hairy
None
linear
oblong
lance
spatula
elliptical
ovate
obovate
triangular
round
arrowhead
heart
kidney
shallowly lobed
palmately
pinnately
deeply lobed
Entire
Serrulate
Serrate
Doubly serrate
Dentate
Crenate
Undulate
Sinuate
Incised
None
Leaf Margins
entire
doubly serrate
undulate
serrulate
dentate
sinuate
serrate
crenate
incised
Asymmetrical
Acuminate
Acute
Rounded
Cordate
Oblique
Saggitate
Hastate
Truncate
None
Leaf Base
acuminate
oblique
acute
sagittate
rounded
hastate
cordate
truncate
Herbaceous
Woody
Aquatic
Shallow water
Floating
Submerged
Exclude brambles
Exclude dandelions
Exclude extinct
Exclude rejected
Exclude drift seeds
Spines or thorns
Stalked leaves (petiole)
Fleshy or succulent
Glossy
Make selection
Reset
Home
Select one Family
Select one Genera
Select one Species

32

Exhibitions provided an opportunity to test this work in a contemporary art context and to see how the ideas communicate through a predominantly visual form. The Isomorphology study was presented in two exhibitions: one in London in 2013 and one in Berlin in 2013/2014 (Fig.29 and Fig.30). Each exhibition was accompanied by a publication (Fig.31) and a collaborative artists' talk[40] that provided valuable interaction with each collaborator. Each was also a focused opportunity for discussion with a public audience while the research was developing. These strands of feedback provided insight into the communicability of each Isomorphology artwork.

A series of Isomorphology inspired publications[41] informed the development of a textual-visual narrative of Isomorphology. Compiling *Isomorphology* (Anderson, 2013h), *Isomorphology: an Introduction* (Anderson, 2013f), and *Isomorphology*[42] (Anderson, 2015a), (Fig.31) aided reflections on the ever-developing processes of Isomorphology (see appendix A.5).

Public talks and events, for example 'Nature Live' (Anderson and Broad, 2013) (Fig.24) and 'Science Uncovered' both at the NHM, provided opportunities to communicate Isomorphology through public speaking in combination with artworks and digital images (see Appendix A.6) to a number of audiences and encouraged the communication of Isomorphology through an accessible and non-didactic format. The NHM Life Sciences department also invited me to give an internal lecture on Isomorphology to NHM life sciences staff[43].

Isomorphology became a helpful tool to navigate both the field and the museum collection and I decided to test Isomorphology outside of the NHM on a number of occasions, including a period as invited artist in residence at the D'Arcy Thompson Museum[44], Dundee and a workshop at the Grant Museum, University College London.

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40 In Berlin with the curator Johanna Zinecker, which focused on Isomorphology and in London with Chris Hatherhill, director of Super-Collider, which focused on Isomorphology and with the mathematicians Tom Coates which focused on our collaboration as discussed in the previous chapter.

41 These books reached audiences outside of the art world through distribution at the NHM, and by artist book centres such as Printed Matter (NYC).

42 The artist's book *Isomorphology* (2015) was selected for KALEID Editions 2015, which will showcase *Isomorphology* amongst a select group of European Artists Books to libraries and curators at the Tate, London, The Museum of Modern Art, New York, The Pompidou Centre Paris and the Victoria and Albert Museum, London. Kaleid Editions also exhibited the book at the Art Academy in London and at Oslo National Academy of the Arts, Oslo (KHiO), 2015.

43 NHM, April, 2013

44 Who later purchased four Isomorphology artworks for their permanent collection.

Based on the Isomorphology study, I was invited by Staffan Muller-Wille to be the artistic lead[45] on the 'The Art and Science of Systematics' symposium in Hannover (Volkswagen Siftung, 23-27 June 2015).

On the impact of Isomorphology

Isomorphology is a practice and theoretical framework that has been shaped by my engagement with a number of scientific institutions and practitioners and by my investigations into the history and philosophy of scientific knowledge. This artistic research can be understood as a practice that engages with scientific practice and institutions and therefore as a strand of the current 'Art/Science' culture. Isomorphology depends on its tools and unique conceptual model and correlates to what Brett Wilson describes as typical to the Art/Science process which 'may not simply be a question of looking for information in a different place (or time) with different detectors, but of learning to see in a different way by creating new conceptual models' (Wilson, 2014: 18).

Isomorphology 'physically' brings specimens in relation to each other in an 'extra-scientific' way. The order that Isomorphology creates does not otherwise exist in the museum. Gathering scientific specimens, in the name of art, is a necessary part of the observational drawing process. Thus, the request to 'draw' rather than observe specimens validates a temporary disorder and intervention of the museum system, which lasts only as long as the drawing process, after which only the drawn record of this active disorder remains. This creates a non-trivial intervention on the existing taxonomic model of the museum. The displaying together of specimens in my work space at the NHM, curated by an extra-scientific interest, generated interest from the scientists who called in or passed by, each time providing an opportunity for sharing ideas and questions.

This spontaneous conversation dimension has been important as a means of sharing the Isomorphology study with scientists at the NHM. Artworks in progress have functioned as excellent starting points for discussion. My position in the Sackler Lab was visible to scientists who passed through the lab from Darwin Centre One (DC1) to Darwin Centre Two (DC2), and this favoured chance meetings with passing scientists who were drawn in to look over my shoulder. A more focused engagement of NHM scientists occurred through a life sciences lecture and through a drawing workshop at the NHM (for details of workshop and lecture see B.8).

45 This involved presenting the Isomorphology concept and practice to symposium participants as an academic lecture and an interactive event.

Schiller once remarked that Goethe's interest in science was contagious (Zajonc,1998:22). I have sometimes felt that the study of Isomorphology has been 'contagious' in the context of the Natural History Museum, as the nature of study demanded scientists to re-order their materials in a new workspace and with new working groups. NHM staff have offered their reflections[46] on how exposure to the Isomorphology study has influenced the way they conceive of their collections and has generated their own 'extra-scientific' questions.

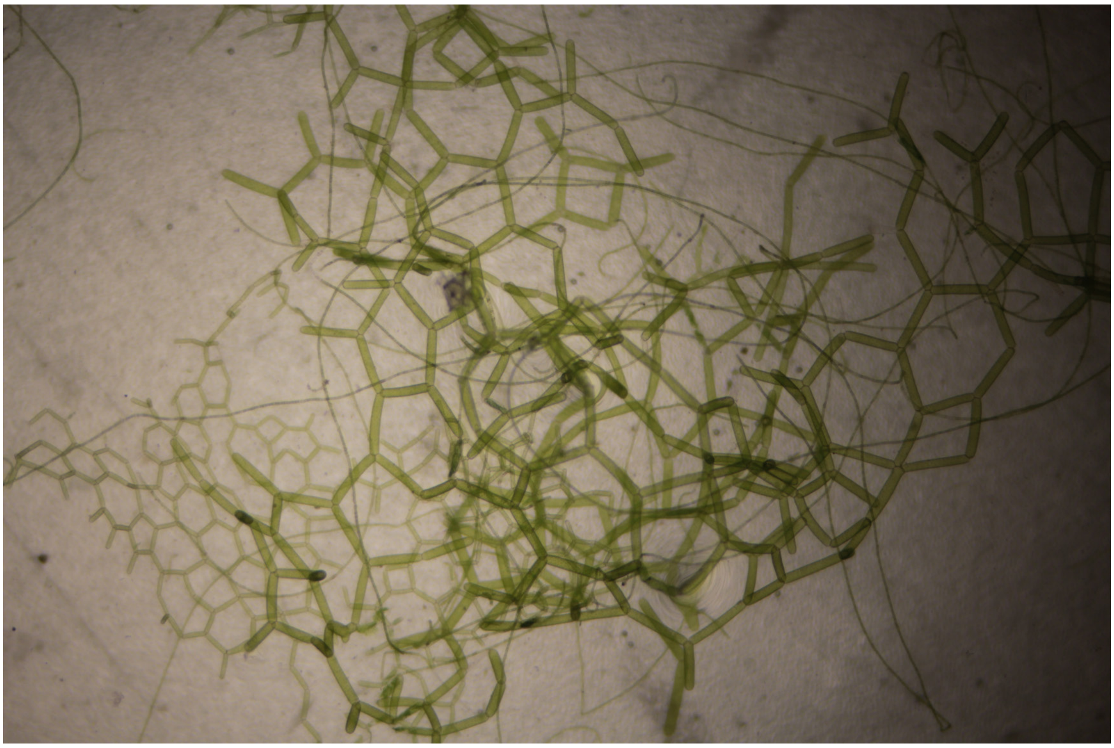

Fig.33.
GAINEY, Paul, 2015. Hydrodictyon reticulatum. Photograph. (© Gainey)

Scientists have often spoken to me after our meeting and commented on observations which have been influenced by their encounter with the Isomorphology study, for example: 'I found a spiral in a spiders tail' (Zoologist, Sackler Lab, personal communication, October, 2013); 'I have started to see hexagons everywhere!' (Gavin Broad, personal communication, June, 2013) and 'you are making us all think about the collections in different ways' (Miranda Lowe, personal communication, May, 2013). Tim

46 See appendix A.7 for reflections from NHM Mineralogist Peter Tandy

Ewin, a paleontologist at the NHM, said he now looks through the collections with 'a different head on' (Ewin, personal communication, 2014). Sometimes the impact of this influence has materialised through emails with attachments of photographs of specimens, for example this moss specimen (Fig.33) showing hexagonal morphology, emailed by botanist Colin French and these spiraling leaves emailed by zoologist Gavin Broad. Isomorphology has also inspired scientists to revisit their interest in art and I invited Peter Tandy, who supplied mineral specimens during the study, to take part in the Isomorphology exhibition in London 2014. After this he continued to bring his artwork to the lab to discuss with me which created a rewarding and unusual knowledge economy as a result of this study.

Examples of the influence of the concept of Isomorphology on scientific practice
Based on workshop feedback that Isomorphology is a useful way to sort and investigate natural forms, I organised more directed conversations with NHM staff to discuss integrating Isomorphology into current scientific practice. From these discussions, it become evident that through further collaboration Isomorphology could be integrated into the following scientific and artistic applications[47]:

1.The integration of Isomorphology as a navigation algorithm into the botanical recording software 'ERICA' (Fig. 32) developed by Colin French (Cornwall Botanical Group) (See Appendix A.8).

2. NHM Zoologist Gavin Broad has started a discussion about the possibility of funding for an art exploration of the NHM collection data which promotes the concept that the collections can be rearranged and interrogated in different ways to the systematic and biographic order in which they are physically arranged. He says:

47 Following these accomplished applications, the potential impact of Isomorphology on scientists and scientific practice can best be understood through the following future projects:
-The application of Isomorphology forms as 'training set' for his computer automated (AI) Taxonomy software programme Daisy (ref daisy paper) developed by Norman MacLeod (NHM Morphologist)
- The development of computer software to use the Isomorphology forms as a way to navigate the NHM digital collections (William Latham – Goldsmiths-creative computing)
- Proposal of Isomorphology themed book to the NHM for development as a product in their shop.
Impact can also be found when googling 'Isomorphology' - artworks and comments appear by people who have become interested in the study.

> Your emphasis on observation and emphasis of taxonomic features through drawing will be seen in some of the approach towards illustrating anatomy of ichneumonid wasps in a book I'm writing. Your philosophy of observation has directly fed the development of the Live Taxonomy activities that I trialled at Big Nature Day. Live Taxonomy will also feature at Science Uncovered and hopefully other activities. Your influence on me has mainly been in opening my eyes to different ways of engaging people with our collections and our science.(Gavin Broad, personal communication, 2015)

3. Permission from Florin (Director) at the Angela Marmot Centre at the NHM, to curate a small collection of animal, mineral and vegetable specimens in, using the Isomorphology forms and symmetries as a basis.

4. Delivery of a collaborative workshop on 'The art and science of systematics' with Gavin Broad (zoologist, NHM) which compared an artistic and scientific approach to taxonomy. In this workshop Gavin presented the standard scientific way of classifying species and I presented an artistic way, through the Isomorphology model (as another way to navigate specimens). Participants were offered the opportunity to explore the role of drawing in species diagnosis. In this workshop we aimed to gain insight into what people observe differently before and after drawing and how the forms and symmetries of Isomorphology could enhance the process of species diagnosis in both an artistic and scientific context (see page 330).

5. Permission to integrate Isomorphology forms and symmetries into hymenoptera collections as 'complementary information in collaboration with NHM zoologist Gavin Broad.

6. Participants in workshops (scientists and artists) have given feedback that Isomorphology has been influential in their scientific practice.

7. The relationship between D'Arcy Thompson and 'Isomorphology' has been recognised by Matthew Jarron:

> Gemma's work poses interesting questions about the relationship between art and science. D'Arcy Thompson sought to show the fundamental growth patterns that connect apparently unrelated organisms, and his work is clearly echoed in Gemma's development of isomorphology and the intricately beautiful drawings

and etchings she creates to demonstrate this (Matthew Jarron[48], personal communication 2015).

In 2013, Jarron invited me to explore the museum collections as artist in residence, after which a series of the works I produced were exhibited at Dundee University and purchased for the D'Arcy Thompson fund collection. In the book *A Glimpse of a Great Vision: The D'Arcy Thompson Zoology Museum Art Fund Collection* (Jarron, Matthew, University of Dundee, 2014- A Glimpse of a Great Vision: The D'Arcy Art Fund Collection- A limited-edition publication celebrating the artistic influence of D'Arcy Thompson) Jarron includes my work amongst a collection of contemporary and historical artists influenced by D'Arcy Thompson. As well as acquiring work by renowned artists who took inspiration from *On Growth and Form* such as Henry Moore and Victor Pasmore, we were keen to engage directly with contemporary artists who were interested in Thompson's ideas and were taking them forward in new and interesting ways. Gemma's work clearly involved considerable skill as well being part of the process of a fascinating academic study, and we were delighted to invite her to spend time working directly with specimens in D'Arcy's collection, some of the results of which we then acquired for the collection (Jarron, 2015).

This book provides comprehensive evidence that Thompson's influence on artists has sustained for almost a century. Later, I was invited to present this research at the International Word and Image Society conference 'Riddles of Form' (directly inspired by DT) at Dundee University 2014.

Conclusion

Isomorphology relates to the work of other artists whose practice engages directly with science and systems of taxonomy, for example Mark Dion, but while Dion's work focuses on critiquing scientific method, or making art works that invite audiences to think differently about the world of science, Isomorphology is distinctive in it's use of drawing as the primary means of observing morphology, which then leads to a novel drawn taxonomy. Isomorphology has focused on developing a cross-disciplinary or 'extra-scientific' tool which can sit between disciplines.

To practise Isomorphology is to play a game of observation; the aim is to derive understanding from direct experience. Training the eye to perceive abstractly and the

48 Jarron is the curator of the D'Arcy Thompson museum in Dundee.

mind to think creatively with a simultaneous and strong connection to the individual specimen is a complex practice. I believe this understanding can be shared with others as a playful educational model, one that engages science whilst allowing an altered perspective. Isomorphology places emphasis on using questioning to liberate form from the confines of (scientific) convention. Isomorphology encourages both learning and 'unlearning'; we are de-constructing inherited taxonomies in order to create new knowledge and new approaches.

While connected to and derived from the observable, Isomorphology functions as a symbolic system and a mode of abstraction. It is an epistemological approach that is coexistent with other epistemological approaches to classification. The Isomorphology study offers a relation between form and classification that is visual and developed in its process of abstracting from nature. The method has shown to develop understanding about the importance of drawing in the identification of morphological features and in relation to classification:

> Though you hide yourself in a thousand forms yet most beloved, at once I recognise you; though you cover yourself in a thousand magic veils, yet, ever present, at once I recognise you (Goethe, 2009:112).

Goethe wrote this poem to express his experience of the *Urpflanze* (see page 142). The practice of Isomorphology enriches the potential observation of nature's forms. As I walk through landscapes, Isomorphology has helped me to read nature's forms: spirals, hexagons and symmetries which emerge amongst numerous plant forms an experience which reminds me of Goethe's own reflections 'I cannot tell you how readable the book of nature is becoming for me; my long efforts at deciphering, letter by letter, have helped me; now all of a sudden it is having its effect, and my quiet joy is inexpressible' (Goethe, 2009: Epigraph)

Isomorphology emerged from the observation of nature and it now feeds back into further observations, a dynamic which ensures that Isomorphology continues to evolve. The following study begins this evolution of Isomorphology, as a new way of seeing which is consistent with aspects of Goethe's morphological approach. Through a detailed analysis of Goethe's morphological method, the next chapter develops and supports a new drawing method, which weaves Goethe into Isomorphology and advances this study of form towards the abstract.

Chapter Five

Drawing with Goethe's Morphology

Introduction

In previous chapters I have explored drawing as a way of knowing morphology, first in contemporary scientific practice and then in artistic practice through the Isomorphology study. This chapter interprets Goethe's conception of morphology and his methodology, making connections between Goethe's approach and Isomorphology. I also place Goethe's concept of morphology within the context of the history of morphological debate (specifically the Cuvier-Geoffroy debate), emphasising links between his work and others, followed by an insight into contemporary concepts of morphology. This is followed by an interpretation of Goethe's 'morphological method', focusing on 'delicate empiricism' and on Goethe's idea that the observation of art enhances the observation of nature. This research is drawn from Goethe's writings[1] through both primary and secondary sources, as it has been important to interpret Goethe directly and to build on the interpretations of others.

Following this, I use this research to turn theory into practice through adapting aspects of Goethe's approach into a new drawing method, which has also been inspired by Isis Brook's interpretation of Goethean Methodology (Brook, 1998, 2009). This material then provides the basis for building an argument that drawing can be used as an epistemological tool for extending and visualising Goethe's concept of morphology.

The drawing method presented in this chapter has been tested in my own practice and shared with artists, scientists (students and professionals) and the general public in a variety of workshop contexts. I conclude with reflection on this practice and the workshops, which is supported by participant feedback and a detailed appendix (B). This chapter prepares the ground for the next stage of artistic practice; in this way it relates to previous and future chapters.

1 Goethe's volumes of Scientific Writings edited by Steiner, 'GA' is the conventional abbreviation of the volumes in his *Gesamtausgabe* i.e. collected works.

Goethe's Morphology

Towards the end of his life Goethe wrote:

> For more than half a century I have been known as a poet in my own country and undoubtedly also abroad; or at any rate I have been permitted to pass for one. The fact that I have busily and quietly occupied myself with nature in all her general and organic phenomena, constantly and passionately pursuing seriously formulated studies–this is not so generally known, still less has been accorded any attention (Goethe in Naydler, 1996: 20)[2].

These seriously formulated studies and his desire to see the 'formless formed, the infinite parade in regular sequence of form' which, he said 'follows from all my work in science and art' led Goethe to coin the term 'Morphology' in 1792 (Goethe in Naydler, 1996: 126).

My understanding of Goethe's morphology and methodology has developed in conjunction with my own artistic practice and through literature including Goethe's *The Metamorphosis of Plants* (2009), *Botanical Writings* (1989), Molder's *Morphology: Questions on Method and Language* (2013), Gilbert and Faber *The elusive synthesis : aesthetics and science of looking at embryos*, Bortoft *Goethe's scientific consciousness* (1986), the interpretation of Goethe's work by Nicholas Boyle *Goethe: the Poet and the Age* (2003), and Seamon *Goethe's Way of Science: A Phenomenology of Nature* (1998).

In the article 'Goethe's morphology: Urphänomene and aesthetic appraisal' (2002), Joan Steigerwald tells us that Goethe did not provide a comprehensive statement of his conception of morphology. This is certainly reflected in the range of accounts and interpretations of this term in the literature, and also leaves Goethe's morphology open to individual interpretation in both scientific and artistic practices.

I found the most concise and complete description of Goethe's Morphology presented by Molder (2013) in the book chapter 'Form as problem: clouds and the sacred vessel':

> Morphology rests on the conviction that everything that exists must signify and reveal itself. From the first physical and chemical elements to the spiritual expression of man we find this principle to hold. We turn immediately to that

2 From Naydler's anthology of Goethe's writings

> which has form. The inorganic, the vegetative, the animal, the human. Each one signifies itself, each one appears as what it is to our external and our internal sense. Form is something changeable, something becoming, something passing. The doctrine of metamorphosis is the key to all of the signs of nature (Goethe in Molder, 2013:172).

Steigerwald defines Goethe's morphology simply as 'the theory of form [Gestalt], formation [Bildung] and transformation [Umbildung] of organic bodies' (2002: 295). Goethe conceived morphology as having a distinct place amongst the sciences not with respect to its subject matter, which was familiar, but with respect to its viewpoint and method. Goethe characterised the science of morphology as a means 'to understand living formations as such, to grasp their externally visible, tangible parts in relation to one another, to take these parts as indications of what lies within and thus to acquire a degree of mastery over the whole through intuition' (Steigerwald, 2002: 314).

For Goethe, morphology was the most universal and hence the most important of the sciences (Goethe in Naydler, 1996: 48). Goethe believed the morphologist should first study completed forms and then study the formative forces that give rise to them. Through close observation of physical structures and processes Goethe believed it should prove possible to arrive at a more interior perception of the form-making power[3] of which they are a manifestation (Goethe in Naydler, 1996: 49). An important distinction made by Goethe was between that which is already formed and thus fixed in character (*Gestalt*) and the formative process (*Billdung*). Goethe's morphology was characterised by striving to reach beyond the fixed form (*Gestalt*) to the dynamic (*Bildung*)[4]. He saw static form as a momentary phase, an instance, of this formative process, which could be considered apart and in itself only by an abstraction (or when static through death as in the museum object). Rather than reduce phenomena to either structure or process, Goethe wanted to allow both into the science of Morphology that he envisaged. Therefore, Goethe's Morphology aimed to find a principle of order and a guiding thread [*Leitfaden*] through diverse appearances. The drive to establish an alternative ordering principle was in part due to his dissatisfaction with the Linnaean system, which he saw as fragmentary and artificial.

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3 'The German language includes a word for the complex existence presented by a physical organism–*gestalt* - (structured form) but if we look at these *gestalten* especially the organic ones we will discover that nothing in them is permanent, nothing is at rest or defined–everything is in flux of continual motion' (Goethe in Naydler, 1996: 50).

4 From *bildung*, which can be understood in this context as a force or energy, which constantly creates or builds up new forms.

Goethe's concept of morphology was teleological in character, not in the sense of a designing creator, but a concept which involved the notion of a 'final cause'. He resisted the strict Newtonian mechanistic and object-centred strategy of explanation and instead emphasised organisms as phenomena of development and growth. Goethe[5] believed that mechanical models of explanation are inadequate to deal with many processes of the organic realm, 'where the relationship of cause to effect is completely different from that encountered in the inorganic realm' (Lenoir, 1984:19).

Goethe's morphology constituted 'a science of organic forms and formative forces' (Goethe in Naydler, 1996: 47) aimed at discovering the underlying unity in the vast diversity of organic and inorganic phenomena. He proposed that the formative process present in all life could work according to a general plan, and believed it possible to achieve an explanation of living things as varieties of common types. He repeatedly emphasised the guiding 'primordial' form or type as the constant element in any structure, despite variations in the form, age or size of the animal, and in the separation or adhesion of parts. Goethe argued that, in time and through practice, the observer could discover the *urphenomenon*[6], the essential pattern or process of a living thing.

Goethe was interested in how boundaries could be set to nature's structural range through the laws of metamorphosis, which relates to Larsen's concept of the 'morphogenetic alphabet' (Larsen, 1987). Although Goethe did refer to a forming force or *Bildungstrieb*, he believed its action was subject to the laws of metamorphosis or changes of form as determined by the primordial forms (Steigerwald, 2002: 299; Lenoir, 1987: 17-28). Contrary to the Linnaean system, Goethe was interested in establishing similarities rather than differences between organic and inorganic phenomena and created his own model of the morphological method which was the first to express in definite terms the idea of the 'unity of plan' (Lenoir, 1984: 20). Cuvier later adopted this idea as a basis for comparative anatomy.

Goethe's *Urpflanze*

After the publication of his study of the intermaxillary bone in 1831 (Feigenbaum, 2015) and its rather cool reception by the scientific community, Goethe became increasingly

5 Like Emmanuel Kant (1724-1804). In *Critique of Judgement* (trans by J.H. Bernard- Hafner, New York, 1951) Kant described a common schema whereby a 'multiplicity of species may be generated by an amazing simplicity of a fundamental plan' and proposed this could be established through careful 'archaeological investigation' as discussed in Lenoir (Lenoir, 1987)

6 The German prefix *Ur* bears the connotation of primordial, elemental, archetypal; the essential core of a thing.

concerned with the study of botany[7] (Lenoir, 1984). An important theme which ran throughout his morphological study was his long intellectual search for the ideal plant form, which led to his conception of the *Urpflanze* or 'the Archetypal Plant'.

> The Primal Plant is going be the strangest creature in the world, which Nature herself must envy me. With this model and the key to it, it will be possible to go on for ever inventing plants and know that their existence is logical; that is to say, if they do not actually exist, they could, for they are not the shadowy phantoms of a vain imagination, but possess an inner necessity and truth. The same law will be applicable to all other living organisms (Goethe, 1970: 310).

Steigerwald suggests that Goethe's insights into the underlying diversity of plant forms occurred entirely when visiting botanical gardens. Goethe developed his observations of plants in Italy in the botanical gardens of Palermo on the 17 May 1787, where, surrounded by a rich variety of 'new and renewed structures' [*Gebilde*] he conceived the *Urpflanze* (Molder, 2013: 171). In a chapter titled 'Form as problem: clouds and the sacred vessel' Molder considers that this experience was crucial to the development of Goethe's 1790 essay 'An attempt to Explain the Metamorphosis of Plants'. In this text, he offers an account of different parts of the organic body as transformations of an *Urform* by 'the laws of transformation, according to which nature produces one part through another and achieves the most diversified forms through the modification of a single organ' (Steigerwald, 2002: 297). Although not readily visible parts of a plant or animal, *Urformen* were determined through disciplined observation and carefully constructed experiments which cultivated an intuition of the general in the particular. Identifying the leaf as this primordial form or *Urformen*, he then described how the leaf form can be clearly recognized in the seed, and then traced through its successive metamorphosis into the stem, leaves, flower and organs of fructification 'the same organ which expanded on the stem as a leaf and assumed a highly diverse form, now contracts in the clayx, expands again in the petal, contracts in the reproductive organs, only to expand finally as the fruit' (Goethe in Steigerwald, 2002: 297)[8]. Through this statement, Goethe proposed that the stem leaves, sepals, petals and stamens are all appendages

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7 He studied the pharmacological use of plants and the natural history of plants, starting his own collection under the guidance of Friedrich Gottlieb Dietrich (Steigerwald 2002:294).

8 Goethe also referred to the 'Proteus' of nature, but in his case it denoted the primordial form that provided the law for the transformation of form (GA 17:239, Steigerwald: 300).

of the same morphotype[9]; they are all transformations of the leaf[10]. These appendages differ from one another only in shape and a degree of expansion, stem leaves being expanded, sepals contracted, petals expanded and so on alternately. Therefore the primordial leaf [*Urblatt*] offered a guiding 'thread through the labyrinth of diverse living forms' (Goethe in Steigerwald, 2002: 297). In this framework, it is equally correct to call a stamen a contracted petal and a petal an expanded stamen, all are varieties of a single abstract plant form[11]. He also describes the continuous transformation of the embryonic leaf, to establish homologies between plant structures in different stages of development[12]. This designation of the leaf as a transformative and 'transcendental' concept was under the influence of Kant and Schiller (Lenoir, 1984).

When Goethe tried to explain his views on the metamorphosis of plants to Schiller[13] in 1794, he did not use the term *Urpflanze* but spoke of 'a symbolic plant' (GA, 16: 867; Steigerwald, 2002: 297,), which Goethe thought he could sketch for Schiller; that is, make this concept into a concrete, perceptible image [*Bild*]. For Goethe 'the symbolic transforms the appearance into an idea and the idea into an image' [*Bild*] (Steigerwald, 2002: 311). In contrast to allegory, which speaks to the intellect alone, Goethe's *Urpflanze* signified to both perception and intellect and can be understood as an archetypal image of a plant (or a proteus). In *Objectivity* (2010) Lorraine Daston and Peter Galison describe Goethe's vision of the *Urpflanze* as intuited from cumulative experience:

> Hence, an anatomical archetype (Typus) will be suggested here, a general picture containing the forms of all animals as potential, one which will guide us to an orderly description of each animal […] the mere idea of an archetype in general implies that no particular animal can be used as our point of comparison; the particular can never serve as a pattern for the whole (Daston and Galison, 2010: 69).

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9 Morphological type.

10 Contemporary plant science recognises stem leaves, sepals, petals and stamens as transformations of the 'meristem' rather than the leaf, although the principle is the same.

11 Goethe's belief in the unity of plan led his work on the vertebral nature of the skull, proposing that the skull is composed of a number of vertebrae, serially homologous with those of the vertebral column. He tells us that the idea flashed into his mind when contemplating a dried sheep skull in the Jewish cemetery in Venice.

12 Goethe's insights into plant development are still relevant today as recognized in Enrico Coen's article 'Goethe and the ABC model of flower development' (2001)

13 Schiller (1759-1805) was a philosopher and poet. Goethe represented the conception of the 'symbolic plant' as deriving from direct observation. Schiller objected with : 'that is not an experience, it is an idea' (Steigerwald, 2002: 308), this provoked Goethe's lively response 'I can only be pleased that I have ideas without knowing it, and can even see them with my own eyes' (GA 16: 867-868; Steigerwald, 2002). This claim to be able to see ideas remains problematic, as reflected in contemporary mathematical research (Anderson et al., 2014)

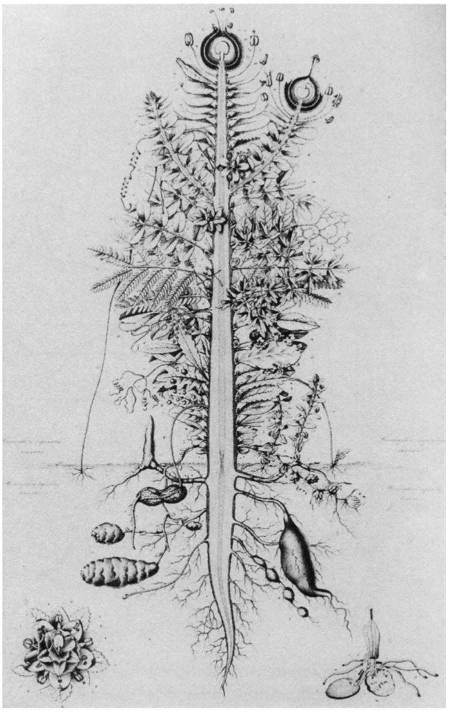

Figure 1.
TURPIN, Pierre Jean François,1837
Representation of Johann Wolfgang von Goethe's archetypal plant form. Woodcut.

Figure 2.
ANDERSON, Gemma, 2013. Representation of Johann Wolfgang von Goethe's archetypal plant form,(drawn from plants at Tresco Abbey Gardens, Isles of Scilly) Copper etching and Japanese inks.

Daston and Galison highlight Goethe's understanding that the conception of the archetype came from observation and emphasise that observations in search of atypical forms must always be made in series, because single observations can be misleading (Daston and Galison, 2010: 70). Goethe aimed to achieve a balance between objectivity and subjectivity, to combine 'diligent imitation and free invention, the tangible and the essential' (Steigerwald, 2002: 307) allowing for a pervasive polarity between a free, subjective, creative impulse and a disciplining, objective[14], structuring element or law.

In the essay 'Experiment as mediator between subject and object', Goethe advises that to obtain empirical evidence, it is preferable to understand the experiment, not as singular event but as a composite of a series of studies (Steigerwald, 2002: 310). Goethe viewed each experiment as 'merely representing a single experience under its most manifold variations' (Steigerwald, 2002: 313) and contended that *Urphanomene* could 'stand before [the investigator] as a result of all experiences and experiments' (GA,16:71; Steigerwald, 2002). Goethe's view of the experiment aligns with my own approach to artistic experimentation in the Isomorphology artworks, where each work is an experiment that culminates in a series of studies.

Alessandro Minelli describes Turpin's representation of the 'universal plant' (1837) [Fig.1], which Minelli calls Turpin's *Urpflanze*, as 'an entangled summary of every possible form of roots, tubers, bulbs, rhizomes, simple and compound leaves, tendrils and flowers' (Minelli, 2015: 14). Minelli suggests that if Goethe had drawn the *Urpflanze* he would have drawn a transformation series embodying the concept 'All is leaf' or *Alles ist Blatt*. Inspired by Goethe's *Urpflanze* and Turpin's 'universal plant', I have drawn my own version of the *Urpflanze* – a composite of my own observations and experiences during a visit to Tresco Abbey Gardens (in 2013) [Fig.2].

Writing about Goethe's concept of the ideal plant form, Stafford notes that '[t]he typical is rarely if ever, embodied in an individual; nonetheless, the astute observer can isolate it from cumulative experience, as Goethe saw the *Urpflanze* (Stafford, 1984: 69). Thus, Goethe's observations collected and solidified into one ideal 'vision' of the plant form.

14 In *Picturing science, Producing art*, (Jones and Galison 2008) Peter Galison outlines how Goethe's struggle to find the Urpflanze was not considered at the time to be objective, as the term 'objectivity' only emerged in the nineteenth century as an opposition to artistic approaches of studying the natural world (Galison, judgment against objectivity: 328, picturing science, producing art).

Contemporary Views on Morphology

Although Goethe's approach could be criticised by scientists as too intuitive and not 'scientific'[15], his instinct did lead to genuine contributions to science through his theory of the metamorphosis of plants. To gain insight into how practising contemporary morphologists understand Goethe's contribution and define their own discipline, I spoke to two contemporary 'morphologists' who I have encountered through this research: Norman MacLeod and Gerhard Scholtz and asked about their understandings of morphology.

As a basis for comparison, this is the *Oxford English Dictionary* (2003) definition of morphology as a noun[16]:

> 1. [mass noun] the study of the form of things, in particular:
> the branch of biology that deals with the form of living organisms and with the relationships between their structures[17].
> 2. a particular form shape or structure (Soanes and Stevenson, 2003).

Gerhard Scholtz (Morphologist/Zoologist, Humboldt University, Berlin) believes that contemporary morphology maintains a strong connection to Goethe's original conception and defines morphology as the ' […] description, comparison, and explanation of structures and their ontogenetic and phylogenetic transformations with an analytical primacy of structures (over function, development, evolution) and against the background of genealogical thinking'. Scholtz considers the discipline of morphology as declining (Scholtz, personal communication, 2014).

Norman MacLeod (Morphologist/Paleontologist NHM London) takes a more mechanistic, hypothetico-deductive view and no longer sees Goethe's conception of morphology as relevant. MacLeod defines morphology as 'anything that has a regular pattern that exists in a spatial dimension'[18]. Unlike Scholtz, MacLeod believes morphology to be in a renaissance period, saying 'everything is morphology' (DNA, Molecular science etc.). Unsurprisingly, Scholtz does not agree with MacLeod's view and argues that if everything is morphology, then the meaning of the term is diluted. He

15 A view held by NHM Morphologist Norman MacLeod, (personal communication, 2014)

16 A naming word, which I think opposes what morphology is about and would be better understood as a verb (an action).

17 Morphology is currently considered as a branch of biology, but not of art. The term is also used in linguistics for considering the way words are structured.

18 Although it is possible to represent different stages in the life cycle as transformation, morphological knowledge helps to order and to compare these spatial patterns to one another.

does agree, however, that structural analysis can be applied to molecular patterns, but he thinks that it should be in the context of an evolutionary framework, i.e., through understanding the transformation of the patterns, which relates back to Goethe.

The conflicting views of Scholtz and MacLeod reveal morphology as a subject of debate in contemporary science. To understand the history and complexity of morphological ideas I will now discuss the famous Cuvier-Geoffroy debate of the early nineteenth century, in relation to Goethe's original concept.

Goethe and the Cuvier-Geoffroy debate

The history of morphology is one of controversy. In *Form and Function* Russell (1982) describes two distinct schools of thought in morphology: that morphology is determined by form (the transcendental view) and that morphology is determined by function (the empirical or mechanistic view) (Russell, 1982: Xxvii.). In what follows, the aim is not a historical reconstruction of the debate, which is beyond the scope of this study. Instead I intend to relate Goethe's morphology to the Cuvier-Geoffroy debate and, in doing so, to map some of the issues at stake in my own approach to morphology, identifying the points of convergence that reveal the relevance of particular aspects of this debate to my own practice.

In *The Cuvier-Geoffory Debate* (circa 1820), Appel (1987) describes how this debate, which came to a head in 1830, represented a fundamental division in biological sciences at the time. The debate was fundamentally whether animal structure should be explained through function or through morphological laws, known as 'the functional' or 'the synthetic' view.

Cuvier, who was professor in chair at the Natural History Museum in Paris, thought function was most important: that is, the animal's needs sufficed to determine its structure. Geoffroy, who was Professor of Zoology at the museum, challenged Cuvier's functionalist view with a new set of doctrines known as 'philosophical' or 'transcendental anatomy', proposing to take comparative anatomy beyond empirical description and classification and make it 'philosophical' by the process of abstraction. The concept of homology was key to a 'philosophical anatomy' which aimed to discover resemblances that could often be obscured to the observer by modifications on the 'type' or 'kind' of form. Geoffroy sought homologies[19] of different animals and this approach

19 German authors started to use the term homology around 1820 (Appel, 1987: 70)

to morphology became an integral part of mainstream French Zoology. This meant that instead of describing each class of animal separately, using different names for different structures in each class, Geoffroy proposed that it was possible to discover a generalised vertebrate anatomy as a single structural plan that could be traced throughout the vertebrates. This particular conception of morphology resonates with the aims of my own Isomorphology project, while also showing a clear link to Goethe's idea that animals could be compared on their skeletal structures and his concept of the *Urpflanze*, which developed the unity of plan concept as a single organ[20]. Through this interpretation Goethe then proposed the 'type' as based on a systematically interconnected set of fundamental organs. He introduced several important defining characteristics of the generalised elements constituting his morphotypes, including position and arrangement, hypothesizing that the position[21] of a structural element is its most constant feature. Goethe therefore intended for organisms to be related as homologous variations on a *bauplan*. The distinction between homology and analogy[22] is significant here in relation to Goethe's work. Homologous parts were those parts in different animals that were 'essentially' the same, even though the parts might have different shapes and be employed for different purposes. The recognition of homologies can be traced back to Aristotle who observed the correspondence between the fin of a fish, the wing of a bird and the arm of a human (Appel, 1987: 70).

Appel describes Geoffroy and Cuvier as individuals with characteristics that match modern stereotypes of the artist and the scientist, respectively: Geoffroy as intuitive and Cuvier as logical. Cuvier favoured an extremely empirical methodology aimed at gathering 'positive facts' (Cuvier in Appel, 1987: 6) while Geoffroy saw the essence of science as ideas and believed that no question should be placed outside the realm of scientific enquiry. Both Cuvier and Geoffroy emphasised the importance of observation 'where our theoretical knowledge of the relations of forms would not suffice, if it were not filled out by our observation' (Cuvier in Appel, 1987: 37). Like Goethe, both believed that observation must supplement theory, as observation establishes empirical laws which complement the rational laws when they are based upon a sufficient number of observations (ibid). Goethe saw this methodological difference as

20 Goethe named *grundorgan* that appears to be single but actually consists of several elements (Lenoir, 1984)

21 Position is defined by the element's functional relationship to the organism as a whole.

22 Owen first proposed the terms, homologue; the same organ in different animals under every variety of form and function' (Russell, 1982:108) and analogue; a part or organ in one animal which has the same function as another part or organ in a different animal.

representing another debate, not one of form and function but one of facts versus ideas or analysis versus synthesis. Daston and Galison acknowledge the 'synthetic' judgment required by Goethe to perceive the 'idea in the observation' (Daston and Galison, 2007: 233) – a trait that has been important to the Isomorphology series (as discussed in chapter two).

Geoffroy intentionally ignored form and function of the parts in isolation, instead concentrating on the connections between parts and a unity of plan or homologous plan for the animal kingdom which preceded particular modifications to the plan to suit functional requirements. In 1820 Geoffroy extended this plan to invertebrates as a 'principle of connections' that became Geoffroy's main guide to determining homological relationships. The principle of connections or 'unity of plan' is the keynote of Geoffroy's work and states that the same materials of organisation are to be found in all animals, and that these materials stand always in the same general spatial relations to one another (Appel, 1987: 70). 'Nature', he wrote, 'tends to repeat the same organs in the same number and in the same relations, and varies to infinity only their order' (Appel, 1987: 71). Geoffroy, like others before him, proposed a new classification system to replace Cuvier's classification of the animal kingdom. He proposed four large groups: Vertebrata, Mollusca, Arcticulata and Radiata (Russell, 1982: 60). Cuvier insisted upon the observable diversities of structural type and his vast knowledge enabled him to gain the majority of support in this debate. Geoffroy's search for homology aligns with the search for resemblance evident in the Isomorphology project.

Goethe and Geoffroy: Kindred spirits

Goethe wrote two essays on the Cuvier-Geoffroy debate, which reveal how he saw the debate as a conflict between the analytic view of nature represented by Cuvier and the synthetic view represented by the *naturphilosophie* movement of Germany, evident in Geoffroy's argumentation. The essays also reveal Goethe's affinity with Geoffroy, who he understood 'seeks to penetrate the cause of the universality of things' (Appel, 1987: 160). I will now expand on Goethe's interest in this debate to give insight into his morphological ideas, many of which I identify with, as demonstrated through the Isomorphology project.

Goethe concluded that Geoffroy and Cuvier represented two poles of a perceptual conflict, and although he believed both the analytic and the synthetic were necessary to ensure the progress of science, his sympathies lay with Geoffroy, saying 'the synthetic manner of treating nature, introduced by Geoffroy into France cannot be held back any longer' (Goethe in Russell, 1982: 65). Goethe saw in Geoffroy a champion of freedom of expression in science, giving weight to Goethe's own ambitions to reform science by appealing to the naturalist, artist and poet. Despite these apparent similarities between Goethe and Geoffroy's thinking, it is thought that Geoffroy did not know about Goethe's work until about 1820. After this, Geoffroy reciprocated Goethe's appreciation as evident in Geoffroy's article 'Essais de zoologie générale: ou Mémoires et notices sur la zoologie générale, l'anthropologie, et l'histoire de la science' (Geoffroy, 1841) which presented Goethe's work as a naturalist and frequently referenced the work of the German 'poet'.

In relation to Cuvier and Geoffroy, Goethe can best be understood as a functional morphologist who also showed many signs of thinking like a developmental biologist, as his view was based on the relationship of ends to means (i.e. the relationship between the whole body and the developmental stages). The link between Goethe's original concept of morphology and what followed was an emphasis on direct observation of form accompanied by a conflict over the primacy of form or function.

As an artist[23], I have used this historical material to gain insight into the kind of morphologist that Goethe's was and to interpret his approach through positioning in relation to the Cuvier Geoffroy debate that reveals morphology as a subject with a history of controversy, to which Isomorphology now contributes. This research has been motivated by the intention to also develop a clearer sense of my own morphological work, which has been inspired by Goethe and which advances through the following interpretation of Goethe's morphological method.

Goethe's Methodology

Later in this chapter, I will build on Goethe's 'phenomenological' approach, by bringing new methods for the direct experience of morphology, most notably through drawing. To being this section, I refer back to Steigerwald's outline of Goethe's morphology as 'the theory of form [*Gestalt*], formation [*Bildung*] and transformation [*Umbildung*] of organic bodies' (GA, 17: 115; Steigerwald, 2002: 295). Although Goethe's approach has been mentioned in fragments in the literature cited here, there has not been a focused presentation of Goethe's methodology, which is the aim of this section[24].

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23 This interdisciplinary research does not claim to be historical or scientific research, rather, it borrows from these disciplines to inform and build artistic practice.

24 Note: the term 'Interdisciplinary' was not used at the time.

In 'Goethe's Morphology: Urphanomene and Aesthetic Appraisal' (2002) Steigerwald describes how Goethe's poetic vision of nature, which began as a view of natural phenomena as a potential medium for depicting human feeling, evolved into a study of minerals, mammalian skeletons and plants. This development was stimulated in the 1780s by his role as administrator in the Duchy of Weimar (Steigerwald, 2002: 292) placing him in charge of the ducal mines and forests led him to serious studies of mineralogy, botany and other sciences. This role cultivated the methods of fieldwork, collaboration and collecting in Goethe's work. One of his first tasks in Weimar was to reopen the copper-silver mine at Ilmenau, which brought him into contact with a group of mineralogists associated with the Freiburg Mining Academy, including Johann Carl Wilhelm Voigt with whom he engaged in a form of collaboration, that inspired Goethe to take up the study of mineralogy and to start his own collection of minerals (Hamm in Steigerwald, 2002: 294). To learn about the subjects he worked with, Goethe read widely but also engaged in many discussions, using conversation as a method for exploring ideas, with colleagues in Weimar and Jena.

For Goethe, observation and intuition were the starting point for theorizing. These observations led to the abstract concept of the *Urform* (Primordial forms) in which thought and experience are collapsed into one. These primordial or general forms hold the potential of specific or individual forms as realised by specific organisms (Steigerwald, 2002: 296). *Urforms* were therefore arrived at through what Goethe called *der spekulative geist* (the speculative spirit), which can be understood as intrinsically linked to intuition. Goethe's science of Morphology then required the method of disciplined observation in order to reveal primordial forms and for making intuitable the dynamics behind the forms and formation of nature.

Goethe's morphological enquiry emphasised an intimate, first-hand encounter between student (or scientist) and object of study. This was both through direct observation and direct handling of the object, which reveals the haptic as an important feature of Goethe's approach. Direct experiential contact became a basis for his understanding as he intended morphology to go beyond the conventions of empirical study. Maintaining continuous experiential contact with the object of study throughout the course of investigation was key to Goethe's approach 'Pure experience' he wrote, 'should lie at the root of all physical sciences' (Goethe in Naydler 1996: 43).

Friedrich Schiller, a contemporary of Goethe and also a poet and playwright characterised Goethe's approach to nature as an intuitive approach, which started from sensory experience and progressed from material and particular things to general laws. He contrasted Goethe's approach to nature to speculative or rational approaches, such as his own, which start from abstract 'a priori' principles, and deduce laws that are then to be demonstrated in the particular. But, Schiller also added an intellectual and inspired intuition to this repertoire, one that facilitates a vision of the general in the particular, a 'genius which under the dark but certain influence of pure reason combines [the given] according to objective laws' (GA 20:13; Steigerwald, 2002). Through this more deductive style of reasoning Schiller was able to translate Goethe's epistemological and aesthetic work into Kantian terminology while Goethe continued to insist on the need to intuit the idea on the basis of the empirically given.

Goethe refers to the term 'genetic' not as the term is understood today - as the science of genes, but rather to seeking the origin or genesis of things. He describes the method as follows:

> If I look at the created object, inquire into its creation, and follow this process back as far as I can, I will find a series of steps. Since these are not actually seen together before me, I must visualize them in my memory so that they form a certain ideal whole. At first I will tend to think in terms of steps, but nature leaves no gaps, and thus in the end, I will have to see this progression of uninterrupted activity as a whole. I can do so by dissolving the particular without destroying the impression itself (Goethe, 1995).

Goethe worked to complement empiricism with imagination in order to see nature as both creator and creation. Goethe advises the use of 'exact sensory imagination' which involves focusing the mind on corresponding motion between the visualization of the mind and the plant. What was successive as empirical experience then becomes simultaneous in the intuitively perceived idea (Goethe in Miller, 2009).

Based on Goethe's strong emphasis on observation and 'direct experience' it is not surprising that his approach has more recently been interpreted through the lens of 'phenomenology' by Bahr, Seamon Bortoft and Zajonc. In the article 'Goethe's way of science: A phenomenology of nature' (Seamon, 1998) Seamon focuses on Goethe's study of colour but draws clear comparisons with methods Goethe developed in his study of other phenomena (plants and animals) in achieving his insights into colour. Physicist Henri Bortoft (1996) argued that Goethe's approach aids an understanding of phenomenon both in itself and as a connected part, a view supported by Zajonc's article 'Goethe and the phenomenological investigation of consciousness' (Zajonc, 1999:427)[25].

Goethe regarded the methods of comparative anatomy as the best approach for the extension of morphological study to encompass plants and animals (or the organic and the inorganic). Goethe's approach aligned more with the discerning of primordial forms, based on the principle of comparing 'all animals with every animal and every animal with all animals' rather than 'comparing animals to human beings' as was traditional in the eighteenth century (Steigerwald, 2002: 301). Through such a comparative method, Goethe believed it would be possible to abstract a general anatomical type [Typus] 'a general image [*Bild*] containing the forms of all animals as potential, and one which will guide us to an orderly description of each animal' (GA 17:233; Steigerwald, 2002: 301), emphasising the skeletal structure of animals as 'the clear framework for all forms' (ibid).

Lenoir describes Goethe's morphology as the 'scientific study of those internal laws of biological organisation'. Goethe believed that each 'type' had an associated domain of forces, or processes and he used the phrase *bauprincipien* (Lenoir, 1984) to suggest that the morphotypes provide the basic structures in which these processes operate. In this establishment of the interdependence and dynamic relations of both structure and process as 'little worlds within themselves' (Goethe in Lenoir, 1984: 24) Goethe argues the impossibility of the phenomena being reduced to either one or the other. Further to this, Goethe's expressed his belief that internal structure was inseparably correlated with external conditions[26]:

> If one enquires into the causes that bring such a manifold of determinations to light, then we answer above all: the animal is formed by external conditions for external conditions; thus its inner perfection and its external purposiveness (Goethe in Lenoir, 1984: 24).

25 This interpretation of Goethe's practice within the context of a 'Naturalistic constitutive phenomenology', which studied how consciousness/perception constitutes things in the world of nature, relies on the assumption that consciousness is part of nature.

26 Once these internal 'laws' (processes) had been delineated (given constitution of form) Goethe viewed the task of zoonomie (biology) to investigate the law-like relationships (abiotic factors) in the external environment that condition the transformation of structure: 'first the type should be investigated with respect to the effect upon it of different elementary natural forces, and how to a certain degree it must conform to general external law ('erster entwurf…' HA 13, p.177- REF). Goethe concluded his 'Morphologie' (1824) with the concept that the entire class seemed to be based on a fundamental of 'anlagen' (facilities) capable of being diversified in numerous directions.

Goethe believed that any interpretation of this 'unity of plan' reached beyond the boundaries of science because of its nature as holistic and therefore interdisciplinary study. In this approach, Goethe aimed to discover the general scheme of the constant parts of organisms, a scheme into which all animals will fit equally well; therefore challenging and reconfiguring existing hierarchical classifications of the natural world; an intention shared by the Isomorphology study. Rather than arguing that morphology was to replace existing sciences of living organisms, Goethe intended morphology to function as an auxiliary science. Drawing upon natural history, which studied form in general and the relation and combination of parts, morphology would link together the considerations that lie scattered throughout the other sciences; therefore complementing sciences which penetrated the internal parts and processes of the organic body, including anatomy, chemistry and physiology, which all deal with isolated phenomena. In contrast, the study of form and formative process of living beings offers a space from which the organic whole could be intuited through direct observation (Steigerwald, 2002: 296). Goethe argued that the techniques he developed for cultivating the perception of pure form in nature could become a model for science and art, enabling the intuition of forms of nature through a similarly disciplined perception.

Goethe believed there was a progress from the study of form as static towards the study of form as dynamic phenomena and this went hand in hand with a progression of perception from observation to abstraction and a conceptual understanding of dynamics. His problem with the study of what is fixed [*Gestalt*] is the exclusion of that which is changeable, 'that is why [the German] language quite properly is accustomed to using the word formation [*Bildung*] for the product as well as the process of production [...] the formed is immediately again transformed' (GA 17: 13-14; Steigerwald, 2002: 302). It is clear that Goethe acknowledged the formative process in the transformation of all living beings, but he left these formative processes, the *Bildungstrieb*, unexplored and unspecified (Steigerwald, 2002: 311). Goethe's morphology was interested in representing the formal constraints or structures upon these processes.

Delicate Empiricism

As anticipated above, an important feature of Goethe's morphological method is what he terms 'delicate empiricism' or the effort to come to know natural form through prolonged empathetic observation, grounded in direct experience. Goethe also articulated a 'rational empiricism' in which 'pure phenomena [...] stand before us as the result of our observations and experiments[27]' (GA 23: 24-25; Steigerwald, 2002: 300). The task of the observer is then to avoid placing too great an emphasis on hypothesising precisely in order to keep the mind open to perceiving or intuiting the ideas and forms operative in nature. In this process of 'delicate empiricism' Goethe advises the use of imagination, inspiration and intuition[28] in a disciplined way, to encounter the phenomena studied (Magnus, 1949: 59).

In the following quote, Goethe describes 'delicate empiricism' as the moment when separation between the knower and the known would cease:

> There is a delicate empiricism which becomes identical with its objects and is therefore transformed into actual theory. But this intensification (steigerung) of spiritual capacity belongs to a supremely civilized epoch (HA, 12:435 in Amrine, 1990: 195)[29]

Goethe's approach emphasised the value of human experience, aiming to intensify and tune this experience (Goethe in Naydler, 1996: 24). One way of looking at the process of Goethean observation is to see it as a honing of the human being as a scientific instrument 'For Goethe the human being is the most powerful and exact instrument if we take the trouble to sufficiently refine our sensibilities' (Naydler 1996: 23). Rather than assuming that we can in some way avoid using human subjective processes to examine the world, Goethe maintains that these subjective processes can be developed so that each observer becomes an instrument and their own mediation of the world. He says, 'It is a calamity that the use of experiment has severed nature from man, so that he is content to understand nature merely through artificial instruments, and by doing so restrict her achievements' (Goethe in Seamon, 1998: 2). Goethe stressed the importance of training and education emphasising that observers are not all equal in their ability to see. Each person must develop his or her perceptual powers through

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27 See Goethe's letter to Schiller, 21 February 1798, in Goethe, 1962-1967, 2:333; and the essay 'Erfahrung and Wissenschaft', completed in January 1798, in GA 23: 24-25.

28 Intuition' is a somewhat misleading translation of 'Anschauung', which
for any German speaker is a word which means more or less what it says: things you can see (and know by the other senses too, in Kant's case) and the faculty for perceiving them. That is the sense in which Goethe uses it, and he therefore means what an empiricist would call 'sense perception', though in normal English usage (eg 'intuitive') it means almost exactly the opposite of 'Anschauung'', i.e. it tends to mean 'knowledge not derived from the senses'. (Lenoir)

29 This quotation of Goethe's texts come from the Hamburger Ausgabe Volumes (Maxim 509 [maximen und reflexionen], and will be cited with the conventional abbreviation 'HA' followed by the volume and page.

effort, practice and perseverance (this was a practice-based methodology). Goethe proposed the trained observer can transform their understanding of the forms of nature, saying: 'The ultimate aim of science is nothing other than the metamorphosis of the scientist' (Goethe in Seamon, 1998: 8). If we assume the human as instrument, then tuning the instrument and practising with the instrument is one of the ways of producing knowledge, and this in turn provokes a transformation in the knowing subject. I will explore this aspect of delicate empiricism in relation to my own artistic methodology.

Studying art to study nature

Goethe spent much of his time in Italy – a period of twenty months during 1786-88 – studying the visual arts. His efforts at cultivating his observation of classical artefacts were intended to feed his attempt to learn to draw and paint. What Goethe transported from his study of art in Italy to the study of nature was not his original idea of an *Urform*, an idea first formed with Herder before his travels to Italy, but it was the method for discerning this primordial form. Goethe studied art as preparation for studying nature. With morphology in mind, Goethe saw a new significance in the artists sensibility: 'masterpieces were produced by man in accordance with the same true and natural laws as the masterpieces of nature' (Steigerwald, 2002: 311). This view may have been encouraged by conversations with Moritz in Rome, whose essay 'On the Plastic Imitation of the Beautiful' (ibid) privileged artistic creativity.

Goethe argued that the speculative tendencies of science could be disciplined through a similar mode of cultivated observation, as disciplined in the subjective tendencies in art; therefore the ideal form in nature could be intuited on a similar basis as the ideal form in art, mainly because works of art are understood as constructed products unlike the self-assembling products of nature. This attempt to model scientific epistemology upon aesthetic judgment proved controversial at the time, but has recently been at the centre of Zajonc's discussion on 'Goethe's way of knowing, […] the philosophical challenge of contemporary physics, and about the role of contemplation in science' (Zajonc, 2014).

This study of the visual arts became significant for Goethe's study of morphology, as he drew direct analogies between his quest for the laws of art and the laws of plant form. Goethe concluded that if he was to uncover the organising principle of plants, it would be through culture and cultivation and through a disciplined perception necessary to see the essential form in both art and in nature. Like the *Urpflanze* was to plants, Goethe held that the ideal form of art, what could be called the 'Artflanze[30]', is not to be found in any particular work of art, yet particular works of art can resemble or present these archetypes. In his view, the ideal archetypes were not the creation of artists but existed prior to all created work as the natural forms of all art. This idea made Goethe's ambition to intuit the *Urpflanze* in nature inseparably intertwined with his ambition to intuit the ideal of art[31].

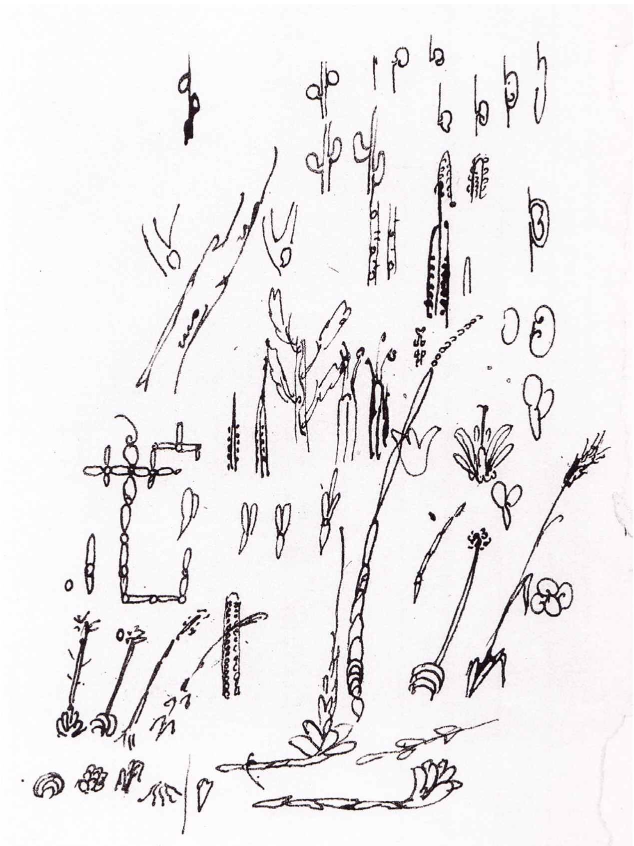

Figure 3.
GOETHE, Johann Wolfgang Von, 1786/1787. Budding, flowering, and branching systems. Pen on paper. belongs to the collection of the Goethe- und Schiller-Archiv/ gsa@klassik-stiftung.de (signature: Corpus Vb Nr. 058/ GSA LV 13, Blatt 161v)

Goethe's problem remained: How to make evident or visible the *Urphanomene* he recognised in nature? In several essays during the late 1790s Goethe outlined his method for evidencing *Urphanomene* in nature, drawing upon the method for appreciation of works of art he was working out in his journal on 'nature and art' (Steigerwald, 2002: 311). Goethe argued that the true or 'ideal' work of art strips its object from 'everything which is not essential' to extract 'the significant, the characteristic, the interesting' (Goethe, 1980: 8-9 in Steigerwald, 2002: 312). Thus describing artworks

30 A term that I have created for the purpose of this argument.
31 In simultaneous agreement and conflict with Plato (Steigerwald).

as models of symmetry and diversity, of rest and motion, of opposition and gradation; moreover, as partially sensible and partially intellectual (ibid). In his notes on scientific method, Goethe argued that the empirical phenomena found in nature need to be raised to the level of pure phenomena 'to represent it, the human mind determines the empirically variable, excludes the accidental, separates the impure, unfolds the complicated'. This suggests the scientific researcher must strive to grasp 'not only how phenomena appear, but also how they should appear'(ibid) and this leads to a question of representation. As a result, I consider Goethe's own method for revealing primordial forms in nature as following acts of construction similar to those of an artist. This is best understood through a comparison to the Isomorphology method as described in the previous chapter and through the carefully arranged drawing experiments, or through Goethe's own drawings of *Urformen* in plants [Fig.3] and the adaptation of Goethe's approach into a drawing method as discussed in later the section 'Adapting Goethe's Approach through drawing practice'.

As Jardine has argued (2001), the terms polarity, enhancement and perfection found in Goethe's studies of colour and plant metamorphosis 'are used as terms of critical and art-historical appraisal to describe the relationship between artworks and their prototypes' (Jardine, 2001:41). In two poems written in 1798 and 1800 'the metamorphosis of plants' and 'the metamorphosis of animals', the relationship between organic and intellectual development is made central. During the 1790s Goethe aimed to develop the relationship between ordering principles for both art and nature through disciplined perception which brought his own imaginative tendencies through a set of carefully arranged experiments and drawings of plants and animals (GA 17:13; Steigerwald, 2002,). In the essay 'the collector and his circle' Goethe argued that perfect art is the result of a balance between earnestness and play. A persistent theme in Goethe's scientific and aesthetic writings is a polarity between an internal creative force and the constraint of form and order, between imagination and discipline, structure and process. This particular aspect of Goethe's method links to the Isomorphology method emphasis on improvisation as combined with direct observation (as described in chapter two).

Goethe and drawing

The visual remained important for Goethe throughout his life, and he expressed his particular preference for drawing, saying 'I should like to lose the habit of conversation, and, like nature, express myself entirely in drawings[32]' (Goethe in Boyle, 2003: 62). Goethe valued the education in drawing and art from his childhood and later studies at the Drawing Academy in Weimar and the University of Leipzig where he had been concerned with the 'correct' method for drawing anatomical forms in the years prior to his trip to Italy[33].

Although Naomi Jackson's article 'Goethe's Drawings' (1938) reveals that Goethe both practised and valued drawing it does not show that any drawings contributed towards his morphological study. Boyle estimates that Goethe produced over 3,000 drawings (Boyle, 2003: 97), and remarks that Goethe drew throughout his life. His preferred media were pencil, charcoal, chalk and ink wash. Boyle does not mention any morphological drawings, instead, drawings of portraits, theatrical scenes and landscapes (Boyle, 2003: 63).

Goethe is noted to have offered to sketch the symbolic plant for Schiller in order to present a concrete, perceptible image to support his concept of the *Urpflanze* (Molder, 2013). It was Goethe's intention to publish illustrated editions of his morphological works. Although he never realised this plan he did produce some drawings and paintings of plant morphology during his Italian journey, complementing illustrations prepared by others for a projected new edition of the Metamorphosis of Plants that emphasised the formal and spatial relationships of the different parts of the plant, with reference to the basic leaf form. In such illustrations, the process of transformation itself, the internal processes by which one form transforms into another and the linkage between the different forms, were not represented. The illustrations focus upon single plants, rather than depicting a series of images in analogy to the array of contiguous experiments Goethe suggested should form the basis of empirical evidence of *Urphanomene*. It is clear that Goethe appreciated drawing as an epistemological tool and although he emphasised that direct observation was essential to study morphology, he did not specifically argue that morphology should be studied through drawing. He did however suggest the suitability of a visual approach:

32 Remark from Goethe conversation, (Boyle, 1980: 73)

33 Boyle recognized Goethe's interest in drawing, describing how Goethe often finished his children's drawings (Boyle, 1980: 54) Goethe also had personal collection of prints and drawings.

> After all, the most desirable principle would be that the researcher borrowed the language employed to describe the details of a certain circle from the circle itself, that the simplest appearance was treated as elementary formula, and that the variety was derived and developed from it (Goethe in Molder, 2013: 173).

To describe the 'details of a circle from the circle itself' implies a directness that drawing can achieve and also articulate. Perhaps what is most interesting about Goethe's drawings and artistic experimentations is that he saw artistic approaches as valid ways to cultivate insight into the study of nature. Implicit to Goethe's thinking was that organic matter is shaped into organs in such a way that each generated part is dependent on every other part for its continued preservation. Goethe aimed to make this thought more precise by examining the different kinds of plant forms but while he did not achieve this in his lifetime, he suggested that a disciplined study of art could be applied to nature to do this (Steigerwald, 2002: 306). Isomorphology could be considered as a disciplined study of art that is applied to nature to reveal different kinds of plant forms and their morphological homologies to other forms, both animal and mineral. Later in this chapter, I build on the Isomorphology method by integrating elements from this discussion of Goethe's morphological approach into a new drawing method.

Although Goethe had aspirations for a visual realisation of morphological study, he was only able to realise morphology through language during his lifetime (Goethe, 2009). Illustrations of his ideas by others were inconsistent with his vision and therefore represented his words rather than act as a substitute for his images: Only he could have created images of his morphology. The adaptation of Goethe's approach into a new drawing method proposed later in this chapter advances a visual interpretation of Goethe's ideas. The approach is not an illustration of his ideas, but a visual adaptation of Goethe's 'delicate empiricism' which combines imagination, intuition and observation.

Goethe's Morphology and Isomorphology

The intention and approach of Goethe's morphology provides a basis from which Isomorphology has developed. Isomorphology builds on Goethe's morphology by establishing and visualising a set of form species or *Ur* forms and symmetries that can be observed in animal, mineral and vegetable species. Although Goethe was open to comparing animal, mineral and vegetable morphology, his morphology did not aim to construct a system for the natural world, rather, Goethe describes any 'system of nature' as a contradiction in terms:

> Nature has no system; it has life, it is life and succession, life and transformations of form from an unknown centre to an unknowable circumference. The observation of nature is therefore endless, whether one wishes to investigate an isolated part or whether one wishes to pursue the traces in all directions (GA, 1982, 13: 35 in Molder 2013: 175).

Although Isomorphology is not aiming to find archetypes and does not have teleological motivations, it does employ homology as an organising principle and relates to Goethe's drive to identify patterns and processes[34]. In approach, Isomorphology shares an intention to intuit morphology through direct experience (an ability which comes through practice). For example, perceiving the spiral forms from a plant's arrangement or the hexagonal forms from a bee's honeycomb, first through observation and then through abstraction, as *Urs*. Unlike Goethe's Morphology, the Isomorphology study emerged from and is manifest through drawing. Through drawing, the form species of Isomorphology become visible, as drawing facilitates the abstraction of form from observation and the perception of 'the idea in the observation' (Daston and Galison, 2007: 58) through training and practice.

Isomorphology recognises that each organism manifests as an individual not a universal, and like Goethe's morphology, requires methods that move between the abstract (general) and the empirical (specific), each informing the other. In the Isomorphology study the 'type' is the abstract and the conceptual is transposed onto the specific through a kind of 'delicate empiricism' of empirical practice. In the method outlined in this chapter I have placed attention on Goethe's idea of the archetypal plant and relationship of parts to the whole organism. This emphasis has evolved the focus of Isomorphology from a study of whole things to a study of parts, from macro to micro and then back again.

The Goethe-inspired drawing method facilitates a move from observation of the morphology or the 'Isomorphology' of the whole organism towards an understanding of the Isomorphology of the 'parts' of the organism. Inspired by Goethe's delicate empiricism and use of homology as an organising principle, Isomorphology has used drawing to investigate the morphology of whole body specimens at the NHM. This drawing process generates questions of form and function which Goethe suggested would naturally emerge from morphological study, such as 'how can we experience and

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34 Which is explored in the later Isomorphogenesis chapter.

draw form as both static form and dynamic process?' and 'how does one form become another?'. This method brings Isomorphology from an approach rooted in observation or its own 'delicate empiricism' towards a more conceptual view of form, resulting in a partial liberation from an observational study.

For Goethe practice and theory were inseparable: 'every act of looking leads to observation, observation to reflection, reflection to combination… in every attentive look on nature we already theorize' (Goethe in Seamon, 1998: 43). This emphasis on the necessity of direct experience and observation is most important to the drawing process.

In order to gain further insight into Goethe's Morphology, I have integrated and combined ideas from Goethe's Morphological approach with the Isomorphology method and incorporate aspects from the work of Isis Brook, who has also integrated elements of Goethe's approach into her own artistic work. I have tested these ideas through a series of experimental drawing workshops in both an art and science context (See Appendix B). Through this chapter and through artistic practice, Goethe's influence continues to manifest itself in my research and practice, most notably through the development of a new drawing method that is presented in detail in the following section.

The Goethe drawing method

In the paper 'Goethean science as a way to read landscape' (Brook, 1998), Brook aims to adapt Goethe's approach in order to further artistic research into the nature of landscape. Building on this, in a subsequent paper 'Dualism, Monism and the Wonder of Materiality as Revealed through Goethean Observation' (Brook, 2009) Brook draws upon her personal experience of practising Goethean observation, as a means to come to know the natural world in the following four stages[35]:

1. Perception
2. Imagination
3. Inspiration
4. Intuition

35 Brook also includes a step on naming (which I do not follow), she justifies the act of naming by saying 'This might give us new ideas or other forms of access to our phenomenon or questions we can pose to it in our further investigation. On the other hand, it also gives us more material that we have to set aside in order to really see the plant we should always have a sceptical eye and always return to the primary source for verification'. (, 2009)

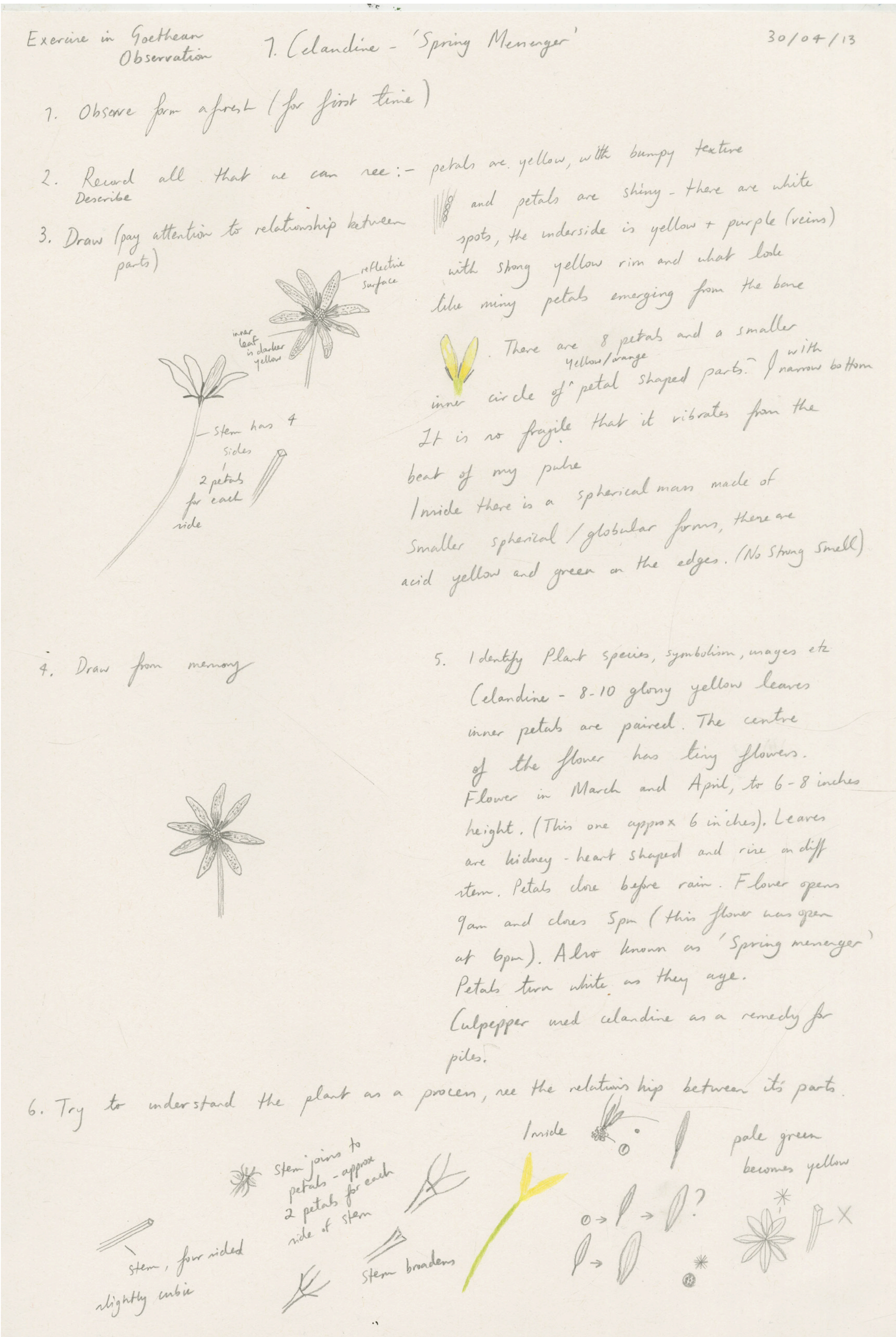

Figure 4. a.
ANDERSON, Gemma, 2013. Drawing of practicing Goethe drawing method: recombining and reconstructing parts. Pencil on paper.

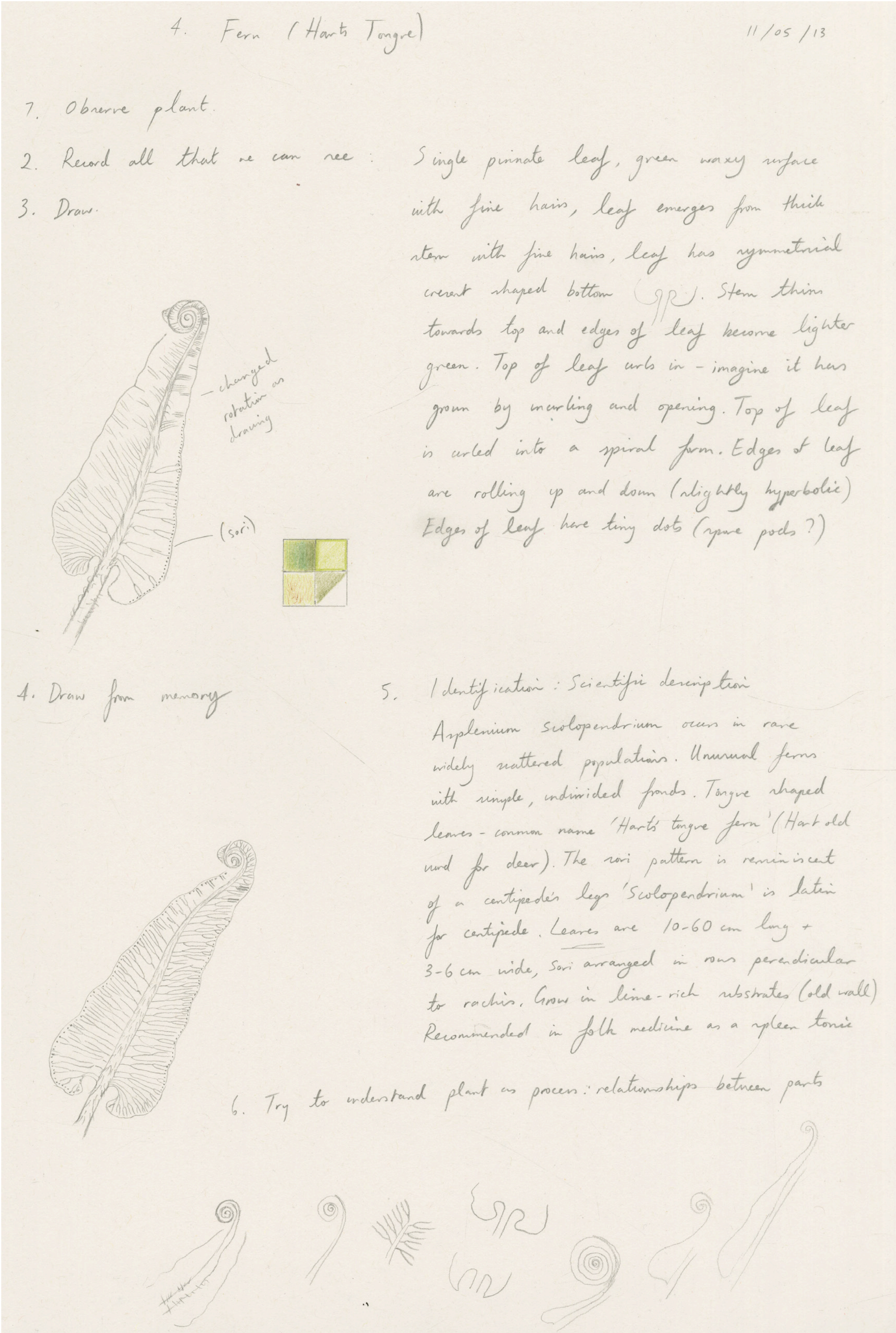

Figure 4. a.

ANDERSON, Gemma, 2013. Drawing of practicing Goethe drawing method: recombining and reconstructing parts. Pencil on paper.

The first stage involves identifying the phenomenon of study (this can be a plant, object, colour, etc) and it is recommended that the choice be based on an instinctive attraction, maintaining a childlike patience and receptivity to the chosen object. The next stages include: 'observing the phenomena freshly, recording all that we can about the phenomena' and 'focusing attention on previously unnoticed detail and the relationship between parts'. Aiming to avoid a habitual approach, Brook advises to ignore some existing knowledge, for example, the names of things, so that the phenomena in question can be seen and described beyond our learned classifications. This approach is in line with Goethe's thinking 'how difficult it is though to refrain from replacing the thing with a sign, to keep the object alive before us instead of killing it with a word[36]' (Brook, 2009: 33).

Building on Brook's antecedent, I have adapted Goethe's approach into the following six stage drawing method. The method aims to maintain continuous experiential contact with the object studied and to enhance the observer's awareness of the specimen's morphology.

1. Observe object of study. This stage is a short observational meditation and applies purest observation only and refrains from writing, drawing or naming. The aim is to observe patiently, in order to recognize and challenge existing presuppositions through this practise. After practising the Isomorphology method, this stage may initiate the observation of one or more form species within the object.

2. Describe the object in detail through written and/or notational drawings. Writing about the specimen can include a mix of a poetic and a scientific approach, using analogy, recall, alliteration, resemblance, metaphor combined with empirical and analytical description. It may be possible to handle and rotate the object and describe the form from multiple perspectives. It can be helpful to include notational drawing and to identify the Isomorphology form species[37].

3. Draw object in detail from observation. This stage is informed by the first two stages and involves drawing the whole object and drawing the parts. Attention should be shared between focusing on specific details to focusing on the whole through 'zooming

36 This relates to Foucault's description of the transition from similarity (pre-"classical") to what he calls the "classical age", when words and objects part ways (Foucault, 2012).
37 This is not intended to be complete or scientific or technical which would bring the problem of how to narrow down the fullness of experience in language or words, rather, emphasis is placed on the poetic possibilities.

in' and 'zooming out'. Referring to the form species of Isomorphology may help to identify parts in this stage.

4. Remove object and draw object from memory. This stage involves creating a mental image of object using the imagination and a conceptual recall of the 'zooming in' and 'zooming out' exercise in the previous stage.

5. Draw the parts or morphological characters of the object. This stage involves imagining the morphology of the whole specimen/object 'blowing up' or expanding in space. This expanded view helps to isolate the parts into a range of characters, like an alphabet and similar to the 'form species' of Isomorphology. It is important to sustain thinking and drawing in three dimensions at this point.

6. Draw the parts identified in the previous stage in a new order. This stage involves recombining and reconstructing the parts into a new composite form (Fig.7.b.).

The most rewarding part of the process for me is the shift from observation to abstraction to deconstruction to creative reconstruction: This feels natural and open-ended, functioning as a loop or cycle. As an artist with a background in studying morphology the stages have prepared me to deconstruct the morphology and then to reconstruct these parts using inspiration, intuition and imagination. When focusing on the relationships of the parts to the whole, I am trying to see beyond the form of the object. This kind of perception of general pattern to the individual variation transcends my habitual understanding of form and sees directly to the abstracted or generalised 'type' *bauplan*, or architecture of the plant. The plant's form is liberated from the specific specimen[38] and from any conventional or contextual association as the process of drawing brings about new relations, resemblances and contrasts that 'liberate' form from it's original context. This insight increases my connection to the object and reminds me of Russell's reflection on the importance of observation to develop a more sympathetic view of the natural world 'We need to look at living things with new eyes and truer sympathy. We shall then see them as active, living, passionate beings like ourselves' (Russell, 1982: xiv). Stage five can be understood in relation to Daston and Galison's description of one quality of scientific observation 'Visually and

38 This is different to microscopy because under the microscope we still see a composite form and we are aiming to identify formal elements, and it becomes easier to relate to the morphology of other organisms and to draw as parts that can be freely reassembled.

intellectually the observer pulverised the object into a mosaic of details, focusing first on one, then on the other' (Daston and Galison, 2007: 99). The spaciousness of drawing allows a composite object to be expanded into parts or 'elements', into 'a mosaic of details' (ibid), which can be compared to elements from other specimens and then be creatively recombined through drawing.

The final stage to artistically represent the object by conceptually expanding the parts of the object in space is a means of deconstructing. It is a way of knowing the specimen in greater detail, and a way to begin an investigation of the relation of parts to whole. By drawing parts we 'make visible' and comparable many parts beside each other. Comparing the parts to one another helps the drawer to recognise the variety of formal elements within one whole specimen. This stage of the method generates variations of the 'form species' derived from direct observation through the Isomorphology study. The plant morphology as perceived (through imagination and cognition) and then re-constructed through drawing brings the learning together with imagination, intuition and abstraction. As a result of the continued practice of this method, which builds on the Isomorphology method and practice, the last stage of expanding a whole object into parts has changed the nature of my own daily observations. I see this a valuable result of the method.

> To find yourself in the infinite [...] you must distinguish and then combine (Goethe in Molder, 2013: 177).

The following drawings use the method outlined above and resonate with Goethe's concept of the creative potential of morphological work 'to go on for ever inventing plants and know that their existence is logical; that is to say, if they do not actually exist, they could, for they are not the shadowy phantoms of a vain imagination, but possess an inner necessity and truth' (Goethe in Miller, 2009: 12).

Workshops at the Natural History Museum London[39], The Isles of Scilly and the Natural History Museum, Berlin

The form of the workshop ties in my theoretical and practical interest in Goethe's morphology because, like Goethe, I believe the practice of morphology can connect people to the natural world. Practising this method in a group is a powerful experience that supports individual practice and increases a feeling of connection to the natural world and to other individuals in the group. As told by one participant:

39 A collaboration with the Royal College of Art

> The type of activity that your workshop is, it horizontally cuts across age, gender, and social verticalities and compartmentalizations and it links people together socially, entertains & cures, and helps us imagine new connections between ourselves, it is the best therapy.

The method helped me to make a departure from observation and I wanted to test if the method could facilitate a similar shift towards a more conceptual understanding of form for other people. I conducted more than ten workshops[40] with different audiences in different locations, which allowed me to play with the method, to see how it can be developed and to identify suitable contexts where it could be applied.

I targeted artists, scientists and the general public because I wanted to see if the method could be useful in both artistic and scientific work. I also wanted to see if it could be applied in the museum, the gallery, the university and the field. Workshop locations included the Natural History Museum, London; the Natural History Museum, Berlin; the Drawing Room, London; the Royal College of Art, London; Falmouth University, Penryn and the Isles of Scilly. Audiences included scientists, artists, art students, science students and the general public [see Appendix B].

I began each workshop with an introduction to Goethe's conception of morphology as described earlier in this chapter and gave the example of his Metamorphosis of Plants, discussing the relevance of his insight that 'all is leaf'. I then presented Goethe's concept of 'delicate empiricism' and his idea that the human can be an instrument. I then elaborated through reading excerpts of this chapter and present an example of Goethe's morphological drawing [Fig.3], alongside my own morphological drawings. I emphasised the role of drawing to generate and address morphological questions. During the workshops, I spent time guiding participants through the stages of the method and responding to their questions. This interaction was then developed during group discussions at the end of each workshop about the drawing process and the drawn objects created.

After the workshops, I described this method, the last stage in particular, to morphologist Norman MacLeod at the NHM, including the stages of observation and drawing to deconstruct into a morphological subset. He indicated morphologists call this deconstruction 'atomizing', and that conceptually, in this case, what the artist and the morphologist are doing is the same. Morphologists atomize a specimen into 'characters'

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40 See appendix B.

for the purposes of description and detailed comparison. 'Blowing up' also relates to methods employed by another of my collaborators, the mathematician Alessio Corti as described in the following chapter.

After this conversation I was curious to see if a drawing methodology developed through artistic research could transfer as a methodology that could be applied to both artistic and scientific practice and research. While appreciating the epistemic value of this method through my own practise, I decided to develop the method outlined above into a new series of workshops which could transfer the focus, attention and active engagement of this approach with others. I proposed to test this idea as a drawing workshop with scientists at the Natural History Museum in London and in Berlin. The following section is an account of both workshops and feedback.

Reflections on practice

Sharing this practice through the workshop form has helped me to gain a better understanding of the method. I will now elaborate reflections on the stages of the method based on my overall experience with the different groups and the feedback collected from the participants.

In the first step (pure observation) it is important to consider the relative power of drawing to challenge our pre-existing assumptions. Francis Bacon recommended that we observe the world of man 'as we would approach the world of God' (Bacon, 2004) with the eyes of children that see everything afresh for the first time. Although this is an impossible aim, this stage of the method resonates with the sentiment of Bacon's recommendation.

The second stage (written description) helps to extend observation before drawing which can be useful to challenge the assumptions that we may make when starting the drawing immediately. One participant wrote 'a joy to see' and another asked the functional question 'how did nature do it?' Some participants reflected that it was challenging to move away from a habitual approach.

The third stage (observational drawing) allows for concentrated drawing that builds on the previous stages and prepares for the fourth step, which relies on memory and reveals what the drawer knows about the object. The drawing then becomes evidence of the learning that has taken place in the previous stages. In this 'drawing from memory' stage there was a noticeable tendency to generalise and to compensate

Figure 5a.
ANDERSON, Gemma, 2014. Royal college of art students at the Natural History Museum.
Figure 5b.
ANDERSON, Gemma, 2014. Art school graduates, artists and general public at the Drawing Room, London.
Figure 5c.
ANDERSON, Gemma, 2014. Adult education group at Kestle Barton Centre for Contemporary Art, Cornwall.

for imperfections by making the drawing more symmetrical than the actual specimen. This may be because drawing from memory refrains from the degree of detail that can be attained drawing directly from the specimen. In general participants were much quicker drawing from memory than observation, which I understand as partly due to acceleration of the drawing process without looking back and forth between the specimen and the page. Drawing from observation involves absorbing and digesting the information and drawing from memory involves pouring this information, which has become knowledge, out again.

The fifth step, which departs from observation, requires imagination to expand the whole body in space and then to visualise parts. The forms and symmetries of Isomorphology proved to be helpful to navigate the whole body and to distinguish and identify parts. This stage can be understood as a kind of dissection, reminding me of Berger's reflection 'for the artist drawing is a discovery, it is the actual act of drawing that forces the artist to look at the object in front of them, to dissect it in their mind's eye and put it back together again' (Berger, 2005: 3). Due to the shift from observation to abstraction, participants tended to draw the parts as more two-dimensional than the whole body. This dimensional drop is comparable to the flattening of pattern making, working from and for a three-dimensional body. Based on this tendency, in a later workshop in St Ives, I decided to ask the group to draw at the Barbara Hepworth Museum and Sculpture Garden in St Ives, in order to encourage an understanding of abstract

Figure 6. (a.+b)
Workshop Participants, 2014.
Images of students drawings expanding forms
in space (method step 5)

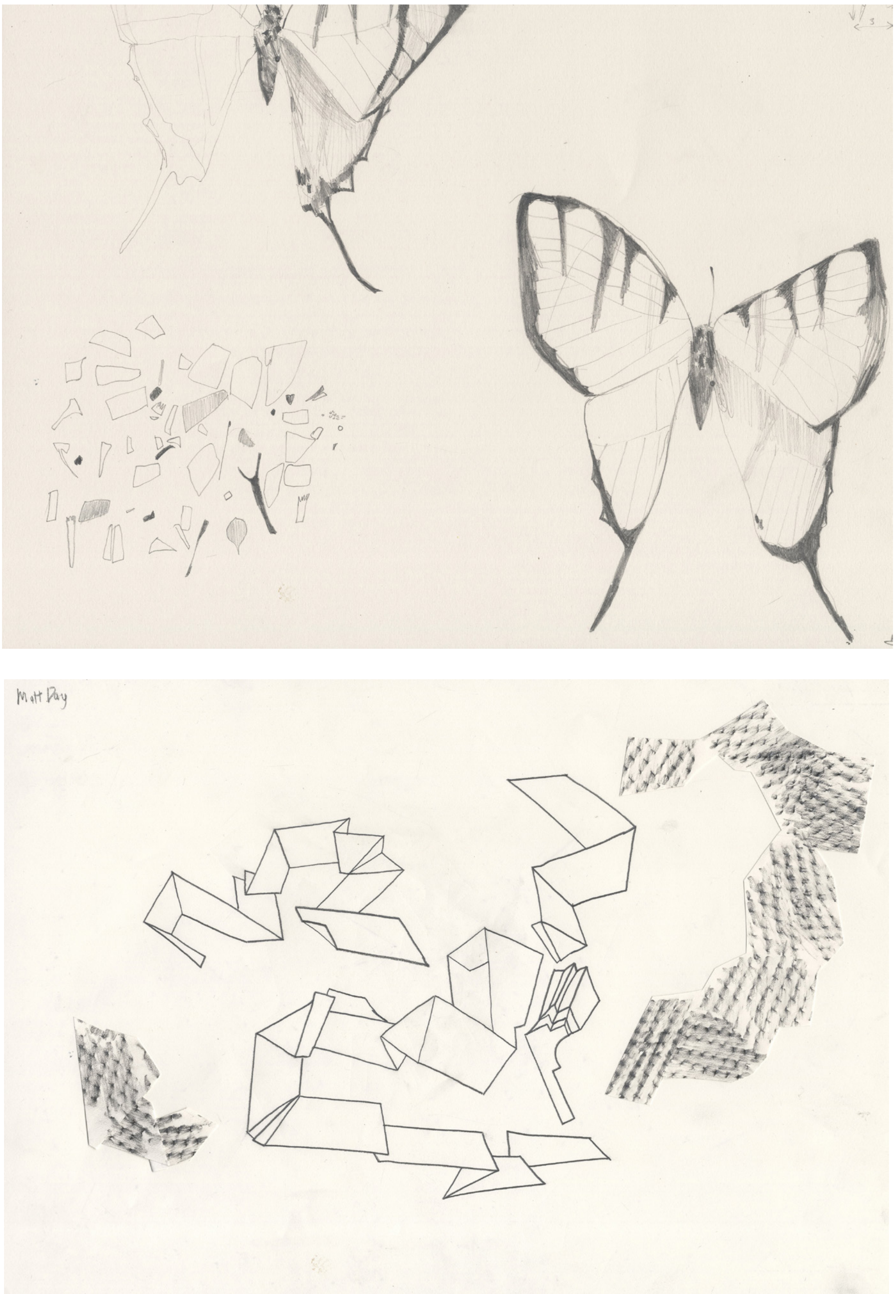


Figure 6. (c+d)
Workshop Participants, 2014.
Images of students drawings expanding forms in space (method step 5)

form as three-dimensional, which seemed to help the group. This exercise provided an opportunity to transfer the understanding of form, which has developed until this point through observing the natural world, to artwork with its own language of form. This exercise employs existing understanding of natural form to enhance our understanding of artforms and vice versa and relates back to Goethe's theory that studying art can enhance the study of nature. As participants draw, I walked around and offered some quotations from Hepworth that relate to Goethe [see Appendix B for quotations].

When drawing and considering the relationship between parts, it is helpful to refer back to Goethe's theory that 'all is leaf'. This helps to observe possible transformations of one part into the next. The following questions also proved helpful in the workshops to stimulate this kind of thinking: how does the stem become the leaf, how does the leaf become the petal and how can this be drawn?

The last stage which involves experimenting with artistic representation of phenomena is where artistic interpretation is very important. This stage demands the consideration of other possible orders for the world around us. This stage which uses intuition and imagination to creatively recombine parts (like form species or building blocks) parallels the creative processes in organic life forms, as nature constantly recombines elementary forms into new orders, compositions and wholes.

It was surprising to witness the possible organisms that evolved through this stage as each participant drew a body or landscape that looked like it may have existed in the past or could exist in the future. There is a joy in creating something new, expressed by participants as the joy of exercising the imagination [see Appendix B] accompanied by a feeling of discovery. This stage emphasised the value of this approach as a repeatable method with different results each time.

Feedback

In each workshop, I initiated a discussion with the group based on the drawings produced through practising the method. At the Natural History Museum in Berlin, we discussed how through drawing, we can create orders that are not possible in the 'natural' world but can be possible through drawing. This led to reflecting on the importance of imagination in science and why we should use our imagination as adults. A number of participants commented that the value of the drawing method was that it helped them to think about the specimen in a new way, with a new perspective. One scientist said 'I looked at the specimen far more closely than I usually would have done'. Another described the value of drawing in more detail 'we normally come to specimen with assumptions and previous knowledge, or a pre-conceived idea of how the specimen should look' and elaborated that this drawing method, which involves observing and then abstracting and dissecting the forms before recombining them meant they could not rely on their preconceived ideas:

> I didn't know much about the specimen I was drawing so I suppose describing the specimen (not scientifically) and drawing how different parts connected helped me know more about it. Whilst the memory part made me think about the key features I'd observed (Scientist).

All participants agreed that drawing from memory was useful as this stage helped them to realise what they did not know about the specimen, which they could then address through the drawing process:

> Drawing from memory made me realise I had not observed my specimen with sufficient level of detail to be able to replicate it exactly. But not having an 'original' to match in front of me gave me the chance to experiment with perspective and arrangement of the plant as I would have wanted to have it in the three dimensional space – which of course does not satisfy gravity! (Scientist).

> The method made me look at every part of the specimen not just selected features as I usually do in taxonomy (Scientist).

At times the feedback from artists and scientists aligned, for example, both artist and scientist commented that the last stage was stimulating:

> I enjoyed the last part where we had to draw an imaginary organism. I really liked the idea, another approach to drawing, that I had not thought of (Artist).

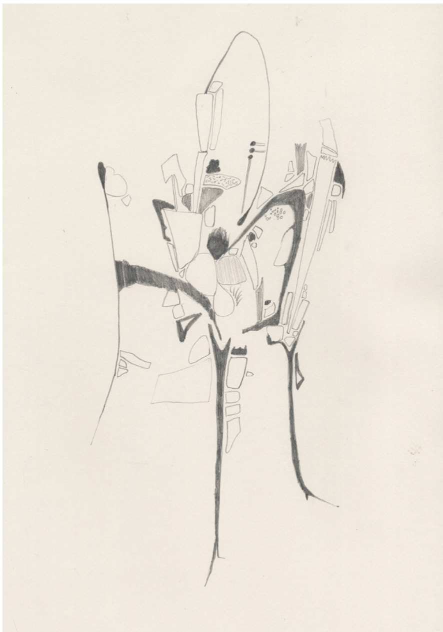
> I most enjoyed the final part (I think this was reconstruction?) as it allowed me to 'let go' and almost characterise the features of what I was drawing without being restrained by what was in front of me (Scientist).

These responses provide evidence that the method is useful or stimulating to people trained and involved in both artistic and scientific practices and professions. Although the same method is practised by artists and scientists, what each individual does with the method is different.

a.

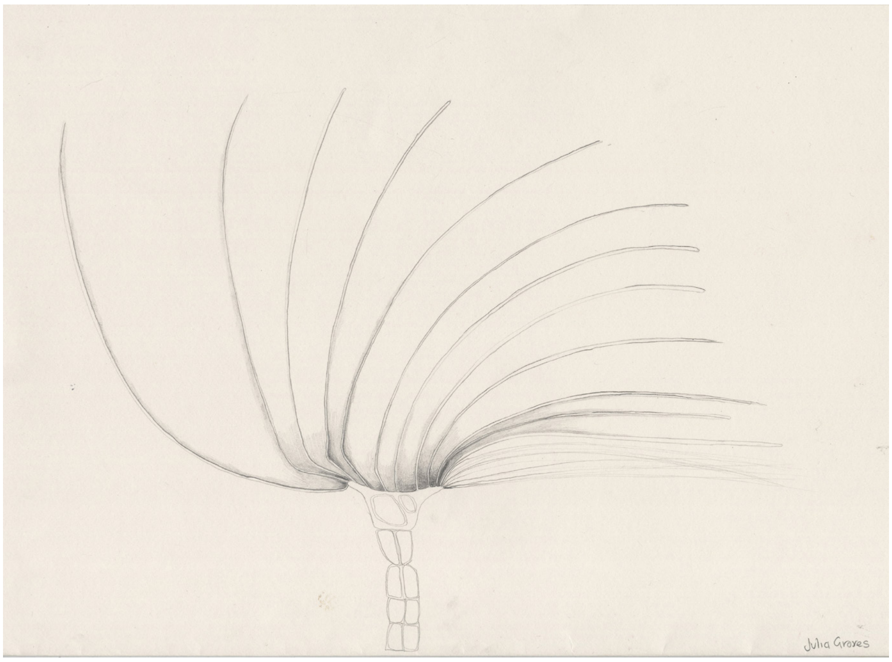
b.

c.



d.

Figure 7. (a,b,+d)
Workshop Participants, 2014. Images of students drawings recombining forms in space (method step 6).
Figure 7.c.
ANDERSON, Gemma, 2014. Drawings recombining forms in space (method step 6).



e.

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Figure 7.(e+f)
Workshop Participants, 2014. Images of students drawings recombining forms in space (method step 6).

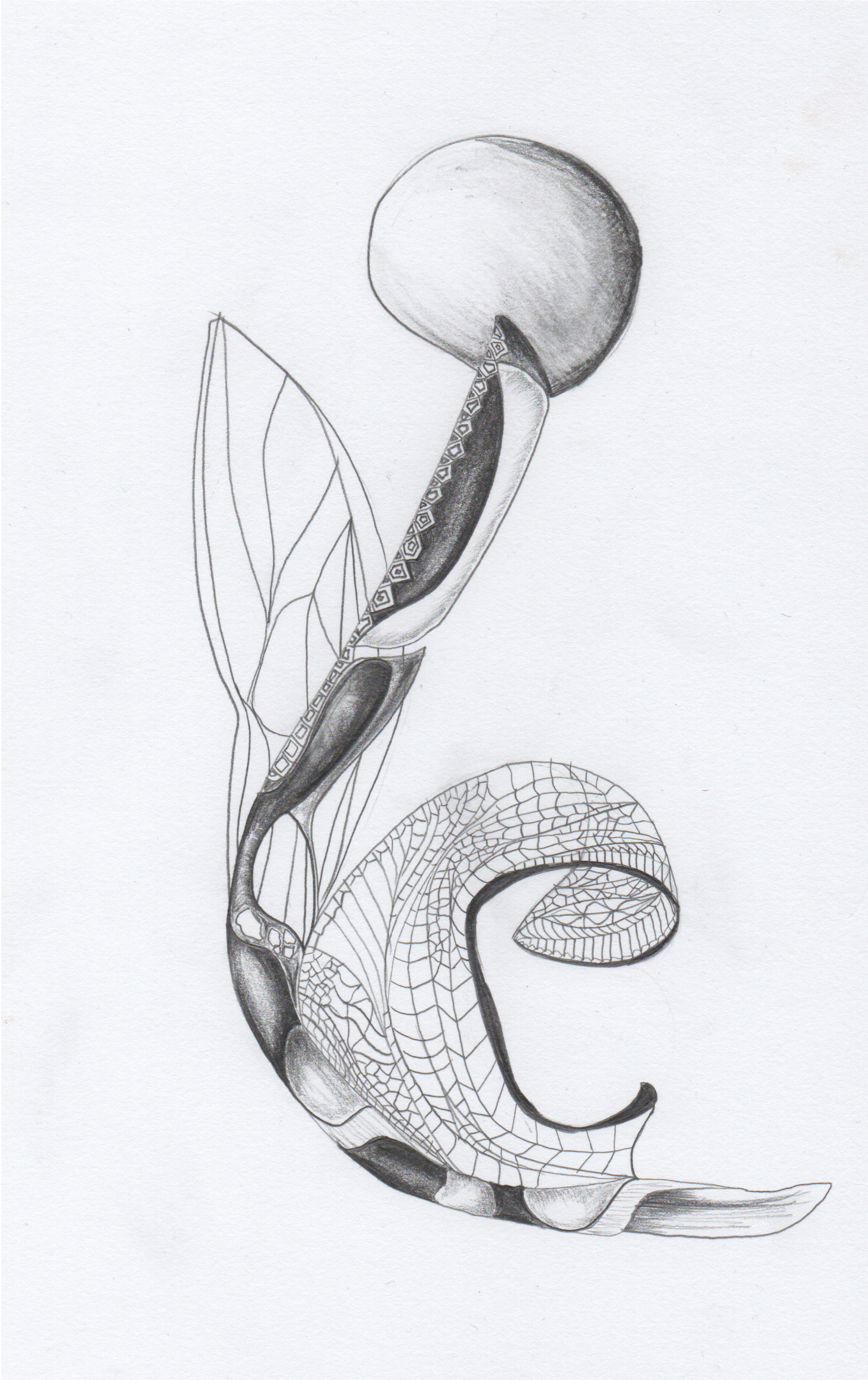

Figure 7. (g+h)
Workshop Participants, 2014. Images of students drawings recombining forms in space (method step 6).

Drawing is useful to address questions of form, which cut across disciplines, as an artistic way of knowing that is useful in scientific practice. This research presents an art practice that is capable of feeding science using drawing methods which allow artistic and scientific work to converge and then to diverge. 'Drawing adds to the repertoire of possible forms of knowing' (Daston and Galison, 2007: 113)[41] to the extent that it blurs the distinction between artistic and scientific practice and therefore transcends the boundaries we associate with the 'two cultures'.

> The method helped me to realise what I was doing wrong. Although in fact I normally adopt a similar strategy, the one you presented is much more functional, and I am sure that forcing myself to go through each of the steps would help me to extrapolate much more information from the specimens I study (Scientist).

Conclusion

This research has built on Goethe's conception of Morphology through integrating my own set of *Ur*-phenomena (the form species of Isomorphology) and providing a new and precise drawing method for representing morphology in the visual (plastic) arts, which complements Goethe's representations of morphology in the verbal arts. The creative possibilities offered by this method have facilitated deeper insights for me into the nature of form. Workshops have proved successful as useful and enjoyable for both art and science participants. This success has been recognised as I have been invited to deliver further workshops at the Natural History Museum, London and the method has also become integrated into a repertoire of workshops at 'The Cornwall Morphology and Drawing Centre'. The value of the workshops as artistic practice in themselves as well as further considerations of their relationship to the rest of the practice and thesis argument, will be discussed in detail in chapter nine 'The Cornwall Morphology and Drawing Centre'.

According to Goethe, Morphology is a science that belongs among many disciplines (Goethe, 1989: 88). In the context of the historical and contemporary controversies around morphology discussed in this chapter, I have argued that to be a morphologist is to study form; meaning that morphological research can be undertaken by any discipline which considers form as it's subject. This study of natural forms and processes is shared by art and science, as each orbits the nucleus of morphology, with different

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41 The motivations of Goethe's and my own work differ in the sense that Goethe's end goal was spiritual enlightenment, clear in his frequent reference to God and the soul. I interpret this as a desire for an expanded awareness, a greater ability to 'be' with nature, transcending habitual human awareness.

perspectives on the centre. Although it has been challenging to orchestrate this method as a workshop in both artistic and scientific institutions and contexts, the practice has liberated form from the confines of conventional scientific museums and institutions and provided an opportunity to disrupt and enrich 'stabilised' practices; scientific and artistic. In my own study of form, as an artist, I am not merely playing the role of a morphologist, nor am I working as a morphologist (in a conventional way) in a science institution. I am a variation on the 'type' of morphologist that can exist. I believe that Goethe's definition of morphology intended that the artist can be a morphologist, a role that I am exploring in this research and practice through the Isomorphology study, which continues to be informed and inspired by Goethe's morphology and draws attention to form as formation, growth and metamorphosis, towards an understanding of the dynamic nature of form.

In the next chapter I follow Goethe's idea that studying art can help study nature through an exploration of Paul Klee's study of the dynamic nature of form through his art. I explore drawing as an epistemological tool for the study of form, first as static and then as dynamic, a study which informs my own endeavor to represent the dynamic nature of form as explored later in this thesis.

Chapter Six

Dynamic Form: Klee as Artist and Morphologist

I have been interested in Paul Klee's work since 2002 when I wrote about it in my BA Fine Art Dissertation and my 2011, publication *Isomorphology: An Introduction* was inspired by Klee's *Pedagogical Sketchbook* (Klee, 1977). The previous chapter, which outlines a Goethe-inspired drawing practice, indicates a shift in my artistic research and practice from a study of form as static towards a study of the dynamic nature of form, from which I gained greater insight into Klee's work. Guided by the themes of formation and growth in Klee's work which resonate with those of my own practice, this chapter has developed in parallel with my own progression from an empirical understanding of form towards a conceptual understanding[1] of form.

The relationship between the Goethe-inspired drawing method discussed in the previous chapter and Klee's became clear during visits to the Paul Klee *Making Visible* exhibition at Tate Modern in October 2013. The talk by curator Matthew Gale[2] (Tate, 2013) prompted a question about the relationship between Klee and Goethe's conception of Morphology: 'Do you recognize a relationship between Klee's art and Goethe's morphology? And would you consider that certain works by Klee, for example 'Growth of the Night Plants', work as morphological studies? As this question was not addressed in the talk or the exhibition catalogue, Gale invited me to discuss the matter further in a meeting at the Tate Modern in December 2013. This later discussion clarified that the relationship between Klee and Goethe's Morphology had not been investigated before and inspired me to write this chapter about Klee's work in relation to Goethe's Morphology.

In this chapter, I interpret Klee's artistic representation of the dynamic nature of form and, based on particular examples, propose Klee as a morphologist. As an artist, I have adopted the role of morphologist (in the Goethean sense as I argue Klee also did) and aim to work with 21st century science to build on Klee's methods and move towards a more contemporary representation of the dynamic nature of form.

1 This can also be understood as the shift from an empirical approach to a conceptual and largely intuitive approach. This is a move from figuration to abstraction- similar to a shift in Klee's own work.

2 Tate Modern, London, 28/10/13, 18.00-19.00.

To gain insight into how others have interpreted Klee's work, I have studied the writings of Richard Verdi, Sara Lynn-Henry, Hatje Cantz and Werner Haftmann, among others. Their work is referred to throughout, as I build my own interpretation of Klee's work in relation to Goethe's Morphology, aiming to answer the question that I discussed with Gale at the Tate Modern. I will outline Klee's engagement with science[3] and consider how his process of drawing can be understood as analogous to biological development. Throughout the text, I will highlight particular art works, to illuminate and develop the themes of formation and growth. Finally, against this background, I will map the biological concept of the 'ontogenetic series' or 'developmental series[4]' on to Klee's work.

Klee's interest in Morphology

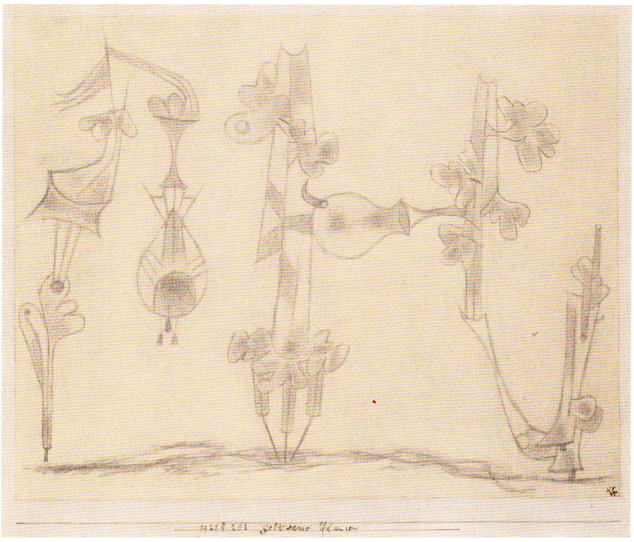


Figure 1.
KLEE, Paul. 1921 Strange plants, pencil on paper, (from Klee's enchanted garden, p.114) CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum.

Between 1892 and 1896, while at secondary school in Bern, Klee attended lessons on 'Morphology and flowering plants', 'Classification of simple plant types according to Fankhauser's principles' (Verdi, 1984: viii), 'Description of individual examples of flowering plants', 'Designing a herbarium' and 'The Linnaean system' (Okuda, 2008:10) where he copied out detailed descriptions of various classes, orders and genera which subdivide the plant world.

3 It is not a surprise that Klee's work as a morphologist came out of a simultaneous engagement with science and art, like Goethe's approach which also required engagement with both fields.
4 The term ontogenetic series would have been current in Klee's era but the term 'developmental series' has been preferred since the emergence of developmental biology.

As a youth, Klee was an avid walker, hiking around Beatenberg alone when he was fourteen. This experience inspired him to collect natural curiosities and flowers for pressing. He continued to make numerous collections: flowers, leaves, roots, seedpods, rocks, crystals, lichens, corals, mollusks, butterflies, seahorses and sea urchins, many of which appear and are transformed in his art (Lynn Henry, 1981).

In his early thirties, especially during the years 1912-1914, Klee became particularly interested in what makes things live, germinate, grow and move; in short, their genesis (Cantz, 2008). Through this interest in germination and formation, Klee's work shifted in a gradual progression from a macroscopic to a microscopic view of form (1912-1914). Klee's appointment at the Bauhaus in 1921 helped him to clarify and communicate his ideas and methods. Many of his students remarked on his ability to make them see nature afresh, as if for the first time and from a viewpoint, that was both scientific and thoroughly creative. Klee reflected on his own methods: 'As their talent develops, guide pupils towards nature, into nature. Make them experience how a bud is born, how the leaf grows, a butterfly unfolds, so that they may become just as resourceful, flexible and determined as nature' (Klee in Verdi 1984: 32). In his elementary painting class Klee taught students to see 'not form, but forming, not form in its final appearance, form in the process of becoming'.

Although it was not possible for Klee to encounter Goethe in person, when Klee moved to Weimar to work at the Bauhaus in 1921, he walked to work past Goethe's Garten Haus in the Ilmpark (River Park[5]). He also frequently visited the Goethe Haus on the Fraunenplan in Weimar, where the original drawings from Goethe's Metamorphosis of Plants and Goethe's colour studies were among the exhibits. Klee also attended a lecture by Rudolf Steiner[6] in Munich in 1908 on Goethe's theory of metamorphosis (Lynn Henry 1981: 61). It is clear from a letter Klee wrote to Katherine Dreir on the 30th March, 1926 that this lecture excited Klee's interest (Kentgens-Craig 1999: 56) and revealed his interest in Goethe's Archetypal plant form. This interest manifested through artworks like 'Strange Plants' (1924), (Fig.1) which made clear reference to Goethe's concept of the *Urpflanze*, as discussed in the previous chapter.

5 'my way to the studio takes me through the gardens past Goethe's summerhouse' (Klee 1961:22).
6 Steiner was a key figure in 'organicist' approaches to education

Goethe and Klee: thinking alike from the 18th to the 20th century

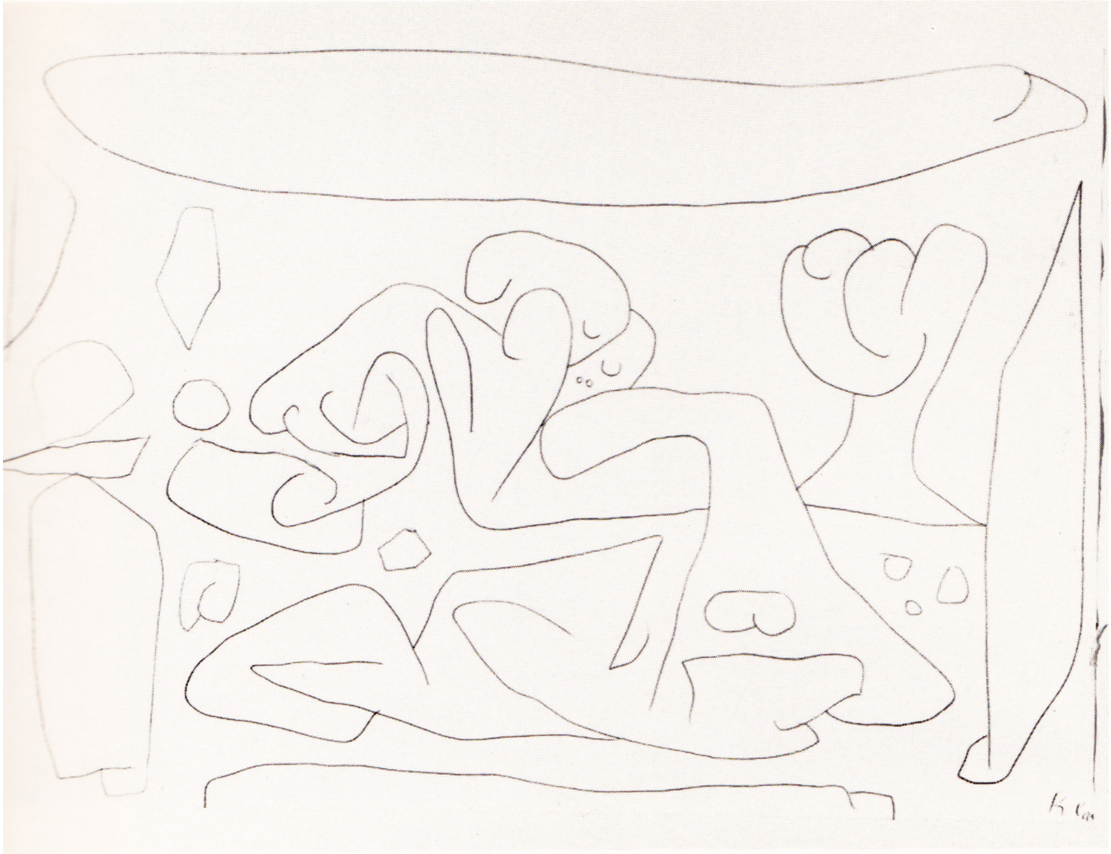
Klee's writings reveal him as a thinker remarkably similar to Goethe, as their views on plant life, on nature study and form often coincide. Goethe and Klee shared a deep interest in nature, plants and the concept of the archetypal form. They also shared a similar methodology rooted in observation. Klee followed the study of nature that Goethe advocated; to learn its laws and inner workings, and his own search for archetypal forms gradually led him to a new way of seeing, as the Art Historian Lynn Henry argues:

> *No attempt to understand the intellectual background of Klee's ideas on nature can ignore the fact that his approach to nature shares more in common with that strain of scientific mysticism which originated from Goethe and which has attracted disciples right up to our own day, than it does with any more recent development in the history of ideas (Lynn Henry 1981: 52).*

For Goethe form was never static, but always in a state of becoming. Klee shared in this view: 'It is precisely the way which is productive, that is the essential thing, becoming is more important than being' (Klee in Lynn Henry 1981: 61). For Klee too, all of creation was essentially a matter of forming, of building and shaping primordial elements and ideas. This realisation could only come from a study of form and through a familiarity with the processes, which brought form in to being, in short, the phenomenon of formation.

Klee viewed the work of art and its creative processes as analogous to the constant metamorphosis of the living world, an idea which he knew through Goethe's writings (Moe, 2008: 61). In a lecture at the Bauhaus in 1921 Klee outlined the concept of genesis as 'multi-layered historicisation linked to artistic work' (Klee 1961:32) he later applied the 'genetic' as a visual concept in his series of drawings 'Infernal park' (1939) (Fig.2).

Like Goethe, Klee's morphological insights emerged through intensive and sustained observational study of as many plant types as possible (Okuda, 2008). Klee's 'Fantasy Flora' series points the mind in the direction of Goethe's archetypal plant. Both Goethe and Klee's application of thought and reflection to their observations led to an intuitive understanding of the common forms and processes which pervaded all plant life. Goethe and Klee both realised that only by penetrating to the smaller units which made up the complex composite plant, could the inner dynamics of nature be confronted, an approach which is also evident in my own Goethe-inspired drawing method.



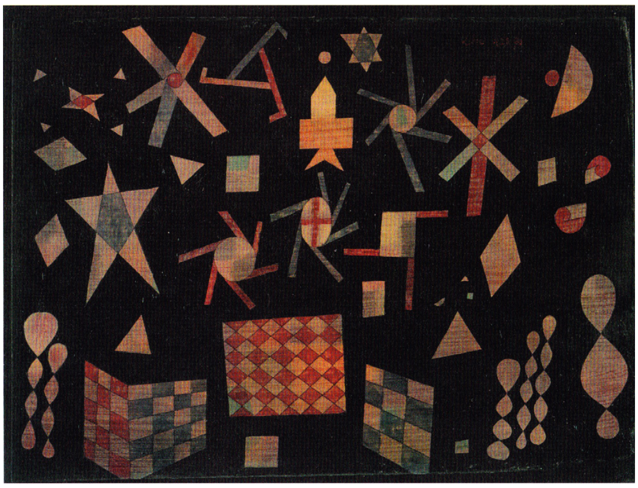


Figure 2.
KLEE, Paul. 1939 The Infernal Park Pencil on Paper, (c. Kunstmuseum, Berlin)

Figure 3.
KLEE, Paul, 1923 Assyrian game. Oil on cardboard, 37x51 cm, (from CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum p.159)

As I showed in Chapter Five, through meditating on the plant's essence rather than its appearance, Goethe discovered that all parts of the plant were essentially modifications of the leaf, proposing 'All is leaf' (Goethe, 1993: 5). Based on my own study and the literature discussed, I consider Goethe and Klee as sharing a similar quest: to discover the underlying features which are shared by all plants. This interest was not to recount *the* history of plants but rather *a* history of *the* plant, looking for similarities between plants rather than differences. As comparative thinkers, they aimed to discover analogies between apparently dissimilar things, an aim which is shared by the Isomorphology study.

Klee and Goethe's reference to the 'genetic treatment' (Haftmann 1954: 150) meant a gradual advance achieved by observing, contemplating, speculating, analysing, penetrating[7] and slowly comprehending objects to such an extent that it is possible to step away from the object and to recreate it in the mind. The observer must look beyond the surface to see the essence of a thing and the forms which lie concealed within. Goethe believed that the essential form of a plant can only be seen if the eye has penetrating spiritual power which he called 'intuitive judgment'. Klee calls this 'visible penetration' (Haftmann 1954:150), consisting of dissecting or visualising the inner working of an object until it is possible to grasp its essence. An image should therefore show not only external appearance or final form, but the process of formation as well.

Klee searched for the 'nature' rather than the appearance of things and the formative process behind the form. He did not seek to represent objects but rather to 'make visible' dynamic process. This quest for the invisible archetype behind countless visible species was accompanied by a desire to uncover the unifying features linking even the most diverse beings, and reinforces the similarity of Klee's thinking to Goethe's (Verdi 1984: 26). This 'linking' does not necessarily imply a scientific relationship, but is better understood under a pluralist framework; in which there are many ways to make relations between things. For Klee, the economy of nature's invention lay hidden beneath an endless array of appearances in an order that remained concealed from the ordinary observer. 'Nature can afford to be prodigal in everything, the artist must be frugal to the smallest detail' (Klee in Verdi: 27). Klee's 'A Priori' flower types do justice to this economy, offering a glimpse of the basic floral types and forms out of which nature has created endless variety. Klee created an order for these basic forms, for example in the artwork 'Assyrian game' (1923) (Fig.3). In his 1923 essay 'Ways of Nature Study' Klee suggested plane sections as a method to penetrate appearance by dissection, a method

7 This 'genetic' approach is similar to the Goethe's 'delicate empiricism' approach outlined in the previous chapter.

that Goethe has also used (Moe, 2008: 56). This knowledge of structure can lead to knowledge of how something was formed and how it functions; anatomy becomes physiology. Goethe recognised one such relationship of form and function as the development of the plant which is governed by the alternating processes of expansion and contraction, and proposed two basic tendencies which shape the growth of the living plant: linear-vertical and helical-spiral.

Klee realized that in the process of coming to terms with the world through images, he had to extract something typical: 'from a series of examples I shall automatically discover the typical' (Klee in Haftmann 1954:150). Klee, like Goethe, wanted to discover primary forms and principles out of which related forms develop, an aim which is shared by my own Isomorphology study.

Goethe's morphological insight was enriched by his preoccupation with natural sciences (especially plant sciences), which he developed into *The Metamorphosis of Plants* and other works. Although philosophically similar, it is important to note that Klee represented the nature of form through visual artworks whereas Goethe realized his studies through literature. Klee's art, like the Goethe drawing method I developed in the previous chapter, achieves a visual approximation of Goethe's conception of morphology. I will now explore the visual dimensions of Klee's work, which allow form and colour to grade through time, through which I propose Klee brings Goethe's morphology into new aesthetic dimensions.

Klee as a Morphologist

The Art Historian Sara Lynn Henry considers the years between 1912-1914 as a turning point for Klee. She describes how after years of observational study, Klee understood the nature of form well enough that he could break the bonds of nature, pick up the pieces and begin to create anew. Until this point, Klee had patiently trained his eye through observing stones, flowers, animals and people. The transformation in his thinking is revealed through this reflection:

> *One day when looking at a shell, it became appallingly clear to me that its existence was not as trivial as I had formerly believed. More and more, I felt that there was a common bond between everything. And then I knew: the world is the power of imagination, imagination – power (Klee in Haftmann 1954: 47).*

In the previous chapter I described a drawing practice inspired by Goethe's methodology. It helped me to understand Klee as a 'visual morphologist' for the following reasons:

1. Klee's observational study accumulated into a morphological knowledge which allowed him to improvise, and follow Goethe's vision of the morphologist 'to go on forever inventing plants and know that their existence is logical; that is to say, if they do not actually exist, they could for they…possess an inner truth and logic'(Goethe in Miller 2009:179).

2. Klee's understanding, both empirical and conceptual, of the common forms and symmetries[8] of animal and plant bodies is evident in many works, for example, in the cell like 'Assyrian game' (1923)(see Fig.3).

3. Klee's work conveys the sense of building (*bildung)*, revealing his view of form as process not product.

4. The works 'Suspended plants'(1921)(Fig.4.a.), 'Growth of the night plants'(1922)(Fig.4.b.), 'Fishes'(1921) (Fig.4.c) (geometric to observed), Fugue in Red (1921) (Fig.4.d) and 'Pottery' (1921) (Fig.4.e.) can be interpreted as 'developmental series' in different ways (as explored later in this chapter).

To begin exploring Klee as a visual morphologist, I will discuss the work 'Komedie' (Comedy 1921, Fig.5) which I was able to observe first hand and draw in the 'Paul Klee' exhibition at Tate Modern. 'Komedie' is composed of a series of totem-like figures: plant, animal and human, which Klee has created through an improvised recombination of formal elements which he knew from his observations of the plant and animal world. The figures appear as alien, unearthly beings and yet they resonate with a strange familiarity. Each individual is a complex composite of segmented parts which, on closer inspection, becomes recognisable as an example of a particular variety of the basic plant forms. These include spiral, tubular, four-fold, radial, spherical, three-fold, eight-fold, budding and bilateral forms. Klee added his abstractions of the rhythmic lines and textures of plants to different areas of the figures. My own research in Isomorphology (Anderson, 2013) helped me to recognise and identify the range of forms in Klee's work. These forms, which can be found in the most common garden plants, are

8 Similar to the Isomorphology 'form species'

recombined with wit and humour to form new plants, people and animals, which do not exist of this world yet could in a world that Goethe imagined:

> *The Primal Plant is going to be the strangest creature in the world, which Nature herself must envy me. With this model and the key to it, it will be possible to go on forever inventing plants and know that their existence is logical; that is to say, if they do not actually exist, they could, for they are not the shadowy phantoms of a vain imagination, but possess an inner necessity and truth. The same law will be applicable to all other living organisms (Goethe: 2009, 4).*

'Komedie' is just one example of Klee's work as a visual morphologist. In it, Klee has realised the potential of the morphological study that Goethe imagined. In 'Komedie' it is clear that Klee is drawing from his own observations, from nature's 'model', and his observations and drawing practice have provided the 'key' to invent with. We can see this invention in Klee's recombination of familiar forms, observed and sourced from nature (especially plants) and although they do not exist in the physical world, they do exist in the theoretical space of drawing and do possess their own internal necessity and order.

In the works 'Fishes', 'Growth of the night plants' and 'Pottery' (Fig.4), Klee shows a number of forms evolving through a developmental sequence. Each stage of the development of the form is graded with a layer of watercolour, the result being an impression of form evolving through the added dimension of time. In this work, Klee is representing the dynamic nature of form: as a moving, formative process. To Klee the concept of mobility meant motion in space and also in time. Klee explored the conceptual and visual possibilities of plants as temporal, moving and transformative entities and reveals his own insight into the formative nature of fruit, flower, seed and root. Representing growth as a progression of form through time and space is at the core of Klee's visual morphology. This ability to improvise with form in a time sequence sets his work apart from modern time-lapse photography which can only capture a series of instances; whereas the artist can conceive, intuit and represent formative process as a continuum. It is remarkable that Klee developed methods and understanding to represent and therefore communicate this dynamism considering the era's social and technological limitations. Klee's colour gradation method, combined with the gradation of form, emphasises and 'makes visible' nature as a dynamic rather than static reality.

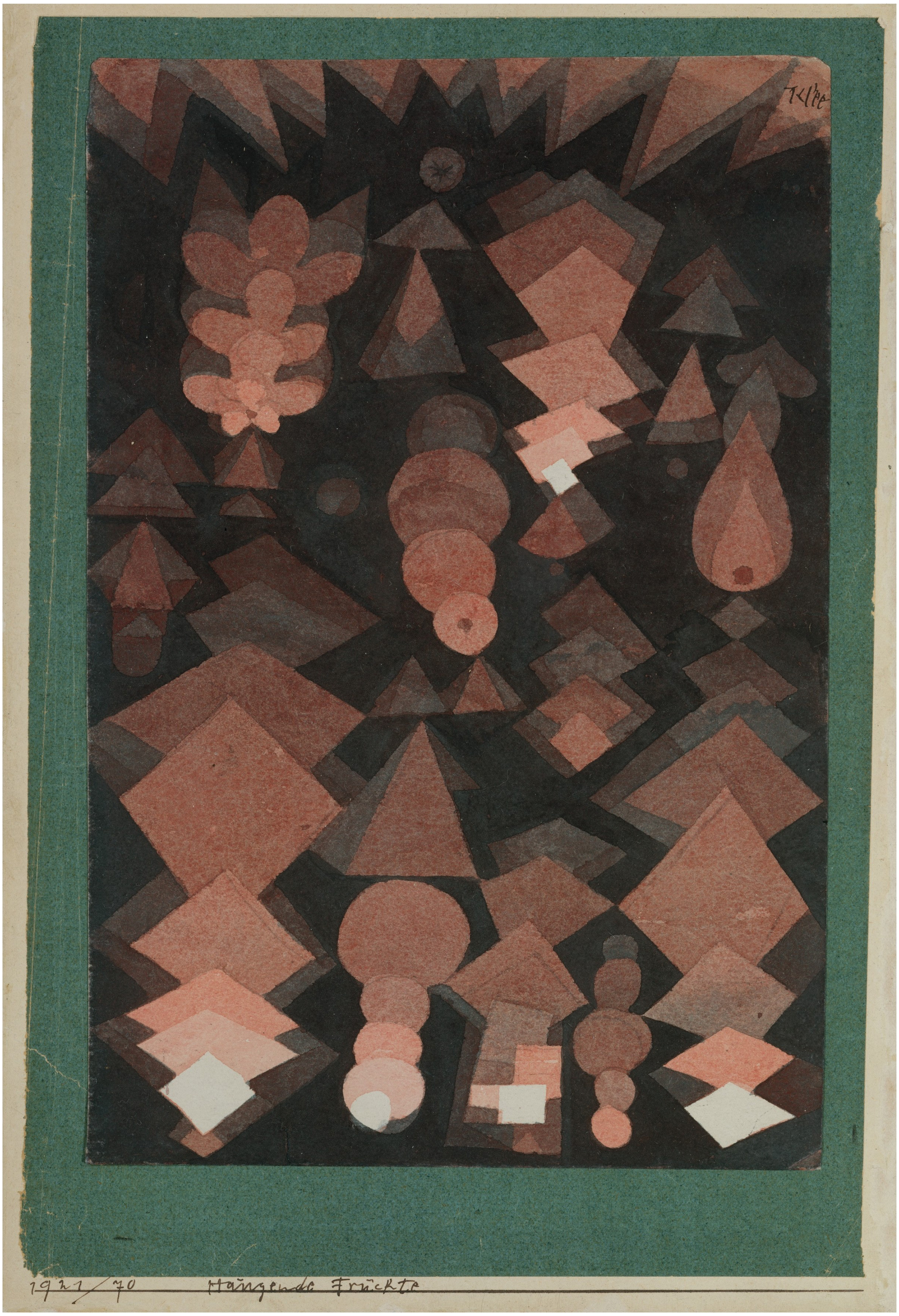
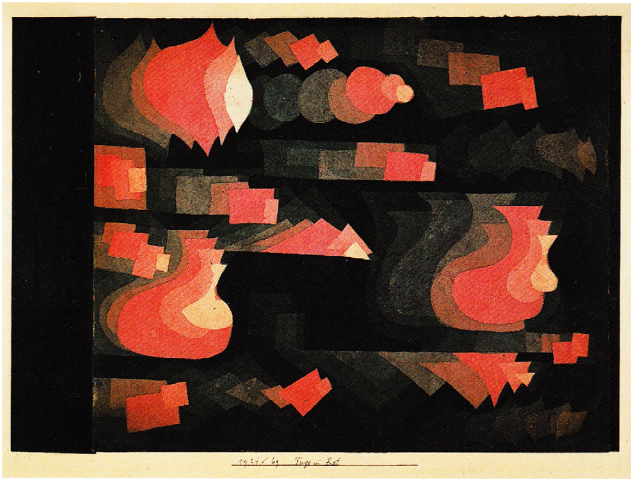


Figure 4.a.
KLEE, Paul 1921. Suspended plants. Watercolour on paper. from CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum

b.

d.



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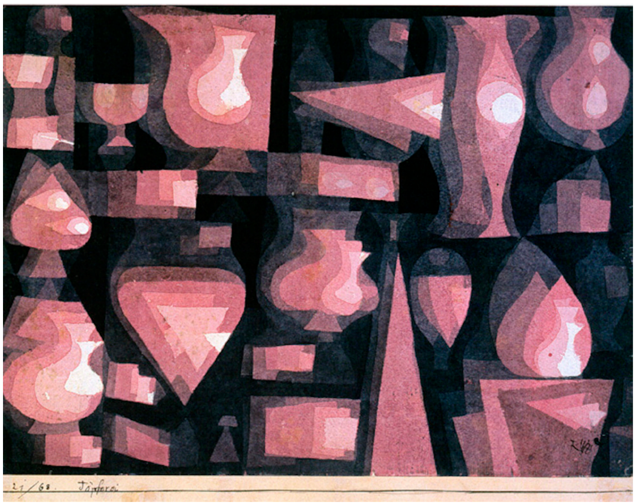
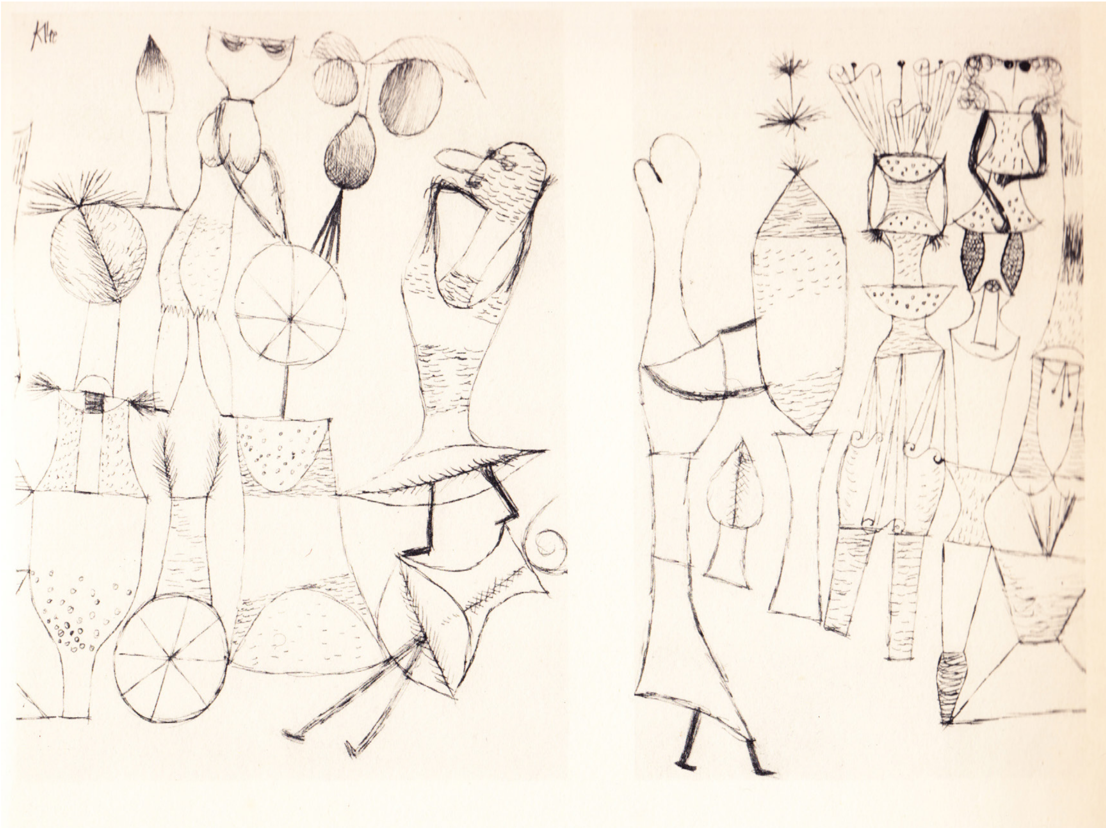


e.

Figure 4.b.
KLEE, Paul 1922. Growth of the night plants. Oil on cardboard, 47.2x33.9/34.1cm, Bayerische staatsgemaldesammlugen, pinakothek der modern, Munich (from CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum p.159)
Figure 4.c.
KLEE, Paul, 1921 Fishes. Watercolour on paper, (from the mind and work of paul klee, haftmann, p.64) HAFTMANN, Werner. 1954 The Mind and Work of Paul Klee. London: Faber.
Figure 4.d.
KLEE, Paul, 1921. Fugue in red. Watercolour and pencil on paper on cardboard, 24.4x31.5cm. from CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum
Figure 4.e.
KLEE, Paul, 1921. Pottery. Watercolour and pencil on paper on cardboard. 24.4x31.1cm, the Pierpont Morgan Library, New York



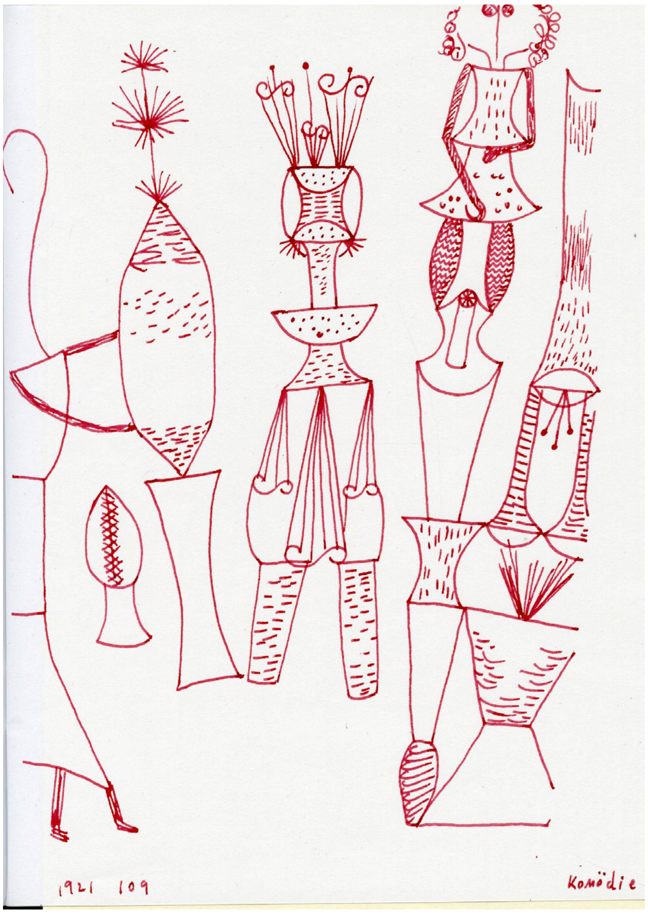


Figure 5.
KLEE, Paul, Komedie, 1921, Watercolour over oil-colour drawing on paper, 12 x 17 7/8 (30.5 x 45.5) and drawing of comedie,
Figure 6.
ANDERSON, 2014, fountain pen on paper. Purchased from Frau Lily Klee (Knapping Fund) 1946 (from Huggler, M. 1965 Drawings of Paul Klee. Borden Pub Co.

Klee's colour gradation method

Klee's colour gradation technique can be understood as a continuous contrasting movement of tone and colour generated through a numerical ratio method (Fig.7) (Klee, 1992: 340). Klee compares the intensity of gradation of colour to sound, describing the movement/ gradation of colour along a 'tonal scale' (mixing each colour for each gradation) and suggesting colour gradation as a signifier of gradual change over time by adding a sense of motion and transformation.

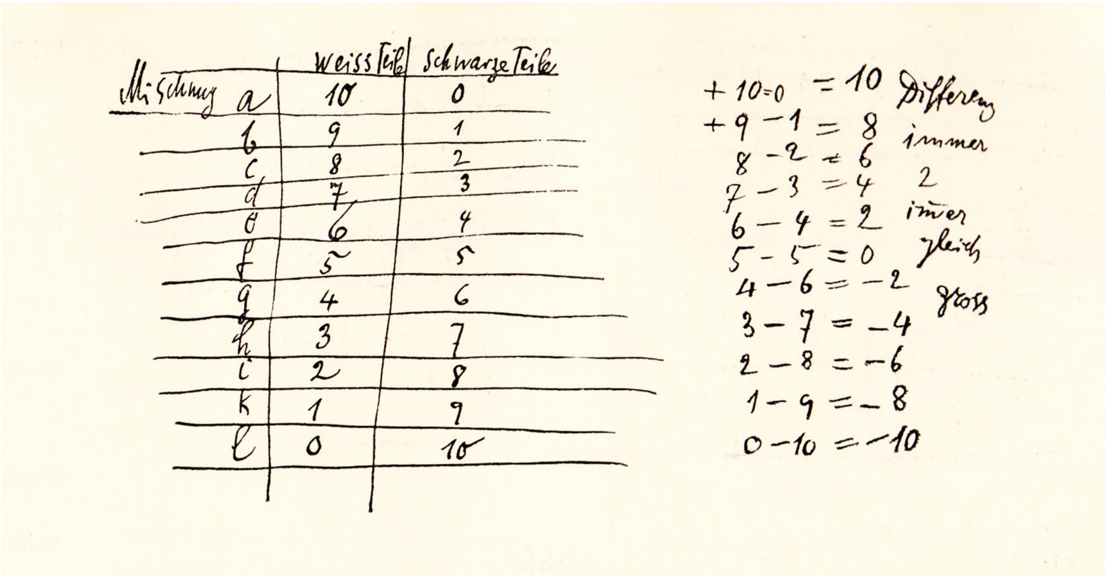


Figure 7.
KLEE, Paul, colour gradation method (diagram), 1932. Pen on paper, 1932, KLEE, Paul. 1961 The Thinking Eye: The Notebooks of Paul Klee. London Lund: New York : Humphries: Wittenborn. p. 317

As part of his teaching at the Bauhaus, Klee drew a colour scale which looks like a musical score he also draws a linear representation of tonal scale and uses proximity and number of lines to create tonality. Further, he describes types of tonal representation as: standing, gliding (soft or hard), striding (small or large) and leaping (Klee, 1992: 349). He then describes tonal gradation in numerical ratio terms and the 'blending' method where relative black (or colour) increments are applied in one direction and relative white (or complementary colour) are applied in the other direction 'relatively declining rate of black increase and relatively declining rate of white increase' (Klee, 1992: 347). He describes graduated colours as 'scales as artfully ordered movement, reminiscent of the structured division of tones we find in musical scales

[…] tonal action of wide and narrow range' (Klee, 1992: 347). Klee goes on to provide numerical tables to show this colour increase and decrease. The repetition element is the concept of enhancement or dwindling, occurring again at every stage. Klee gives examples of simple variations of colour gradation, changing the directions of lines and shows how colour gradation can work in a non-linear structure, for example as a graded circle or cube.

Klee also uses the musical terms major and minor to describe types of contrast 'direct major contrast/indirect major contrast' (Klee, 1992: 383) – implying that he considered scales as a structural articulations of the movement of natural form (for example, in the work 'Fishes', Fig.4). For Klee, colour gradation also has an emotional charge and tension; he talks of the character and movement as varying from a quiet rise and fall to an open struggle, characteristics also evident in biological movement. Through the colour gradation method, using the dimension of colour, Klee makes a clear analogy with how the development of form might be approached.

> *Exactitude winged by intuition is at times best (Klee, 1949:41)*

The specific works by Klee discussed here can be interpreted as visual realisations of the potential of Goethe's dream of the morphologist - one who knows form and formative processes well enough to 'to go on forever inventing plants' (Goethe, 2009: 4) and Klee followed this sentiment through plant inspired artworks, which formed part of over 9,000 artworks produced in his lifetime. Klee's work, as visual art, with its aesthetic dimensions, brings new dimensions to Goethe's morphology. Klee's ability to 'make visible' the formative and dynamic nature of plants, still surpasses many contemporary scientific representations of living form, which present a static version of a dynamic subject. Klee's work points us towards a dynamic morphology; one which represents growth, time and process, suggesting many possible other realities and a reminder that everything is moving.

Moving away from nature: from observation to abstraction

> *I place myself as a starting point of creation where I state a priori formulas for men, beasts, plants, and the elements for all the whirling forces (Klee in Lynn Henry: 131).*

Klee wanted to bring new combinations of the basic forms of nature into being. I interpret this impulse as a desire to simulate an analogue to nature through artwork,

Figure 8

Figure 9

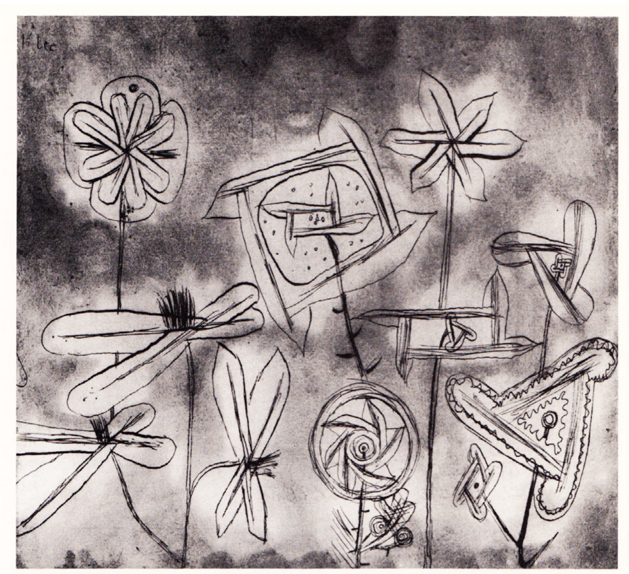


Figure 10.a.

Figure 10.

Figure 8.
KLEE, Paul, Ardent Flowering, 1927. Pen and watercolour on paper on cardboard, 34x46cm, private collection, Germany. CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum.
Figure 9.
KLEE, Paul, 1920 Prehistoric plants. Pen on paper on cardboard. from Huggler, M. 1965 Drawings of Paul Klee. Borden Pub Co.
Figure 10.a.
KLEE, Paul, 1929 Moving blossoms. Pen on paper on cardboard. CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum.
Figure 10.b.
KLEE, Paul, 1917 Sad flowers, pen and watercolour on paper on cardboard. VERDI, Richard. 1984. Klee and Nature. London: Zwemmer.

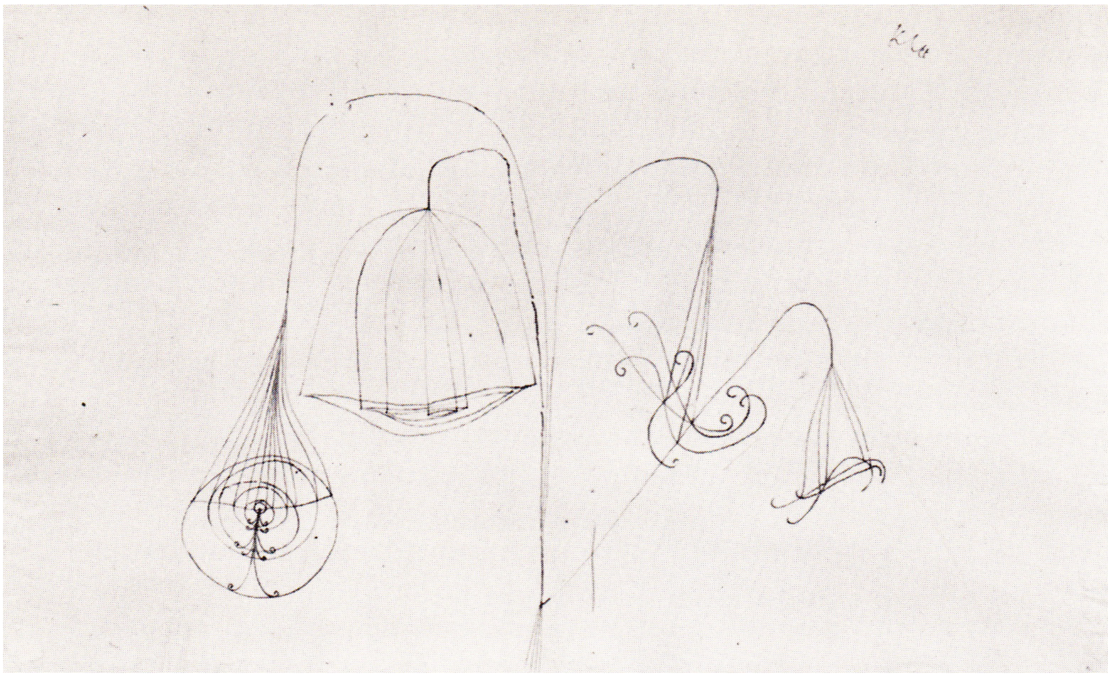
as a way of gaining insight and understanding into the 'nature' of form. To do this, he needed to investigate the forms of nature in order to create an alternative order and analogous universe. 'Wherever I look I see architecture, linear rhythm, rhythm of planes, work on the pictorial means begins with the examination of nature for creative possibilities' (Klee 1902: 15). Comparable to my own process in the Isomorphology study, creating artwork (and all that is involved within that) is Klee's method of coming to know the natural world and of experimenting in unique ways with this new knowledge.

In 'Ardent Flowering' (1927)(Fig.8), a deceptively simple sequence of raising, twisting and unfurling reveals Klee's knowledge of the three basic patterns of growth in developing plants: the vertical, the radial and the spiral. Klee's micro-macro understanding of the natural world is reflected visually with the insight that just as the crown of a tree unfolds around a central axis, so too do the leaves' veins derive from a central system. This insight came through his artistic practice of drawing and observation. He represents these centres of growth as a series of overlapping planes 'that reflect small-scale articulation of the whole' (Klee in Verdi 1984: 211). In 'Prehistoric Plants' (1920)(Fig.9) we see the transcendence of a conventional vision of plant growth and development, representing a move towards a liberation and recombination of plant form, allowing us to question our own conventions and to ask 'what is a plant?'

Klee invents a new order which can exist only in the theoretical space of drawing through the series Fantasy Flora (1920-1923) (Fig.10) which is based on Klee's observations of plant forms as in 'Moving Blossoms' (Fig.10.b) and 'Sad Flowers'(Fig.10.c). In order to make his Fantasy Flora, he did not begin with the forms of exotic wonders of nature; he needed only to learn the basic anatomy of the common flowering plant.

> *For the artist, dialogue with nature remains a condition sine qua non. The artist is a man, himself nature and a part of nature in natural space. Yet the artist is more than an improved camera; he is more complex, richer and wider (Klee in Lynn Henry 1981: 232).*

The explanation for the large volume of plant works by Klee was that formative impulses are more visible in living plants than in the majority of animals. The lower down the 'hierarchy' of life Klee descended, the closer he felt to the very centre of things, to the moment of genesis that he was searching for.



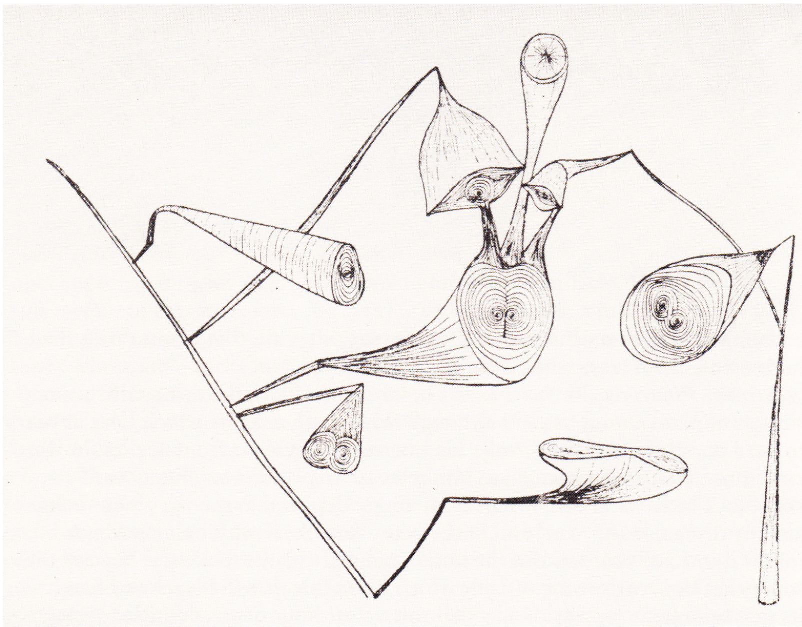
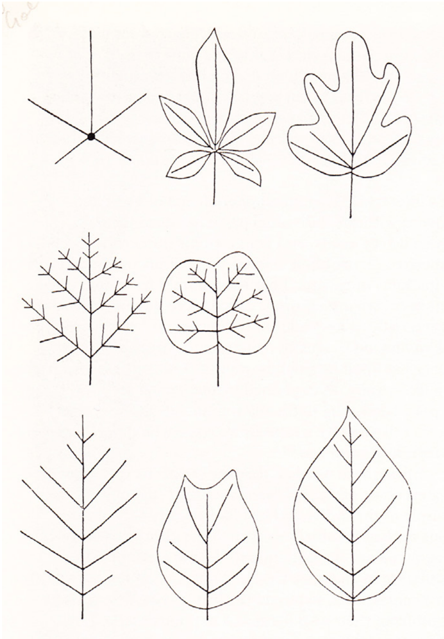


Figure 11.a.
KLEE, Paul, 1927 Quadrupula gracilis. Pen on paper on cardboard from Klee and nature- Verdi- 82) from VERDI, Richard. 1984. Klee and Nature. London: Zwemmer.
Figure 11.b.
KLEE, Paul, 1927 Family matters. Pen on paper on cardboard, VERDI, Richard. 1984. Klee and Nature. London: Zwemmer.148)



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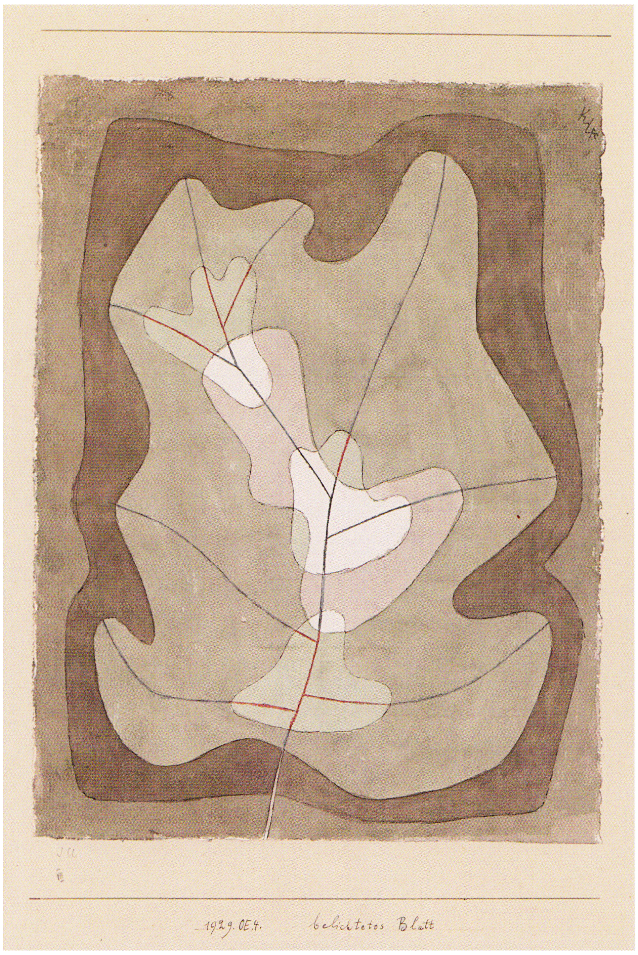

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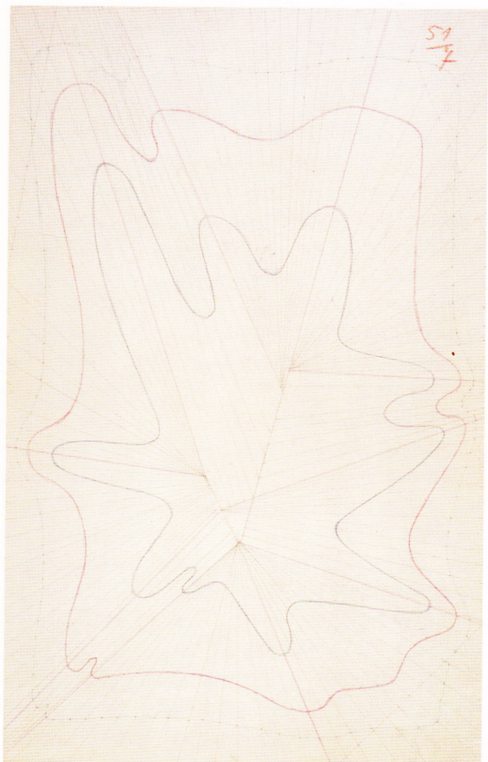


13.

Figure 12.
KLEE, Paul, 1929 Illuminated Leaf. Pen and watercolour on paper on cardboard, 30.9x23cm, (zentrum paul klee, bern.) (from, CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum, p.33

Figure 13.
KLEE, Paul, 1929 Negotiated curves (varial). Pen and watercolour on paper on cardboard, 32.8x20.9cm, zentrum paul klee, bern. (CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum, p.32)

Figure 14.
KLEE, Paul, 1932 Pedagogical drawings of leaves. Pen on paper, (from VERDI, Richard. 1984. Klee and Nature. London: Zwemmer: 108)

Klee's improvisational method was first used in his figurative work of 1912 when he began to construct figures, plants and landscapes by intuitively recombining a series of basic forms. In order to improvise[9] he needed to employ his knowledge of growth and to create extemporaneously with an artistic approach that emphasised both the genesis of the image and the vegetal process of becoming. Klee called this approach of combining the appearance of the subject intuitively with its essence or inner structure 'psychic improvisation' (Klee, 1923).

Klee learnt the basic morphological and geometric types from nature, and endeavoured to indicate their formative processes through art. He often built his works gradually (images) through the repetition and layering of these basic, germinal elements. Germinating and growth proved to be Klee's favourite motifs, his spiral flowers can be seen in the process of unfolding and rotating. Sometimes Klee would reveal this inner structure by an 'x-ray' view as in *Quadrupula Gracilis* 1927, (Fig.11.a.) and *Family Matters* 1927 (Fig.11.b) or by cross-longitudinal sections in which forms are liberated and exchangeable, for example, in 'Flowers' (1915) plants become geometric configurations. Klee saw natural forms as progressions of geometric forms; for example, he presents the palm leaf as a progression and regression of angles on the basis of a circle divided into 24 sections.

Klee used this method to create 'illuminated leaf' in 1929 (Fig.12), and 'negotiated curves' 1929, (Fig.13) combining two different types of branching as the basis of the improvisation. Klee derived and sorted certain types of forms and basic principles from nature, which could be used by his art and design students (Klee, 1992: 259). He saw life forms as composite creations and believed that, by reduction to separate parts, he could offer an understanding of nature's creative methods which could be applied through artwork. His search for these constituent parts led him to reduce the forms he worked with to a series of rhythmically repeating units, analogous to the single cell in nature. Klee's ability to intuit form was recognised by Foucault who stressed the evidence of knowledge of the most fundamental elements in Klee's work, saying 'and these elements, apparently the simplest and most spontaneous, those that are hidden and never seem to appear, it is these that Klee spreads out across the canvas' (Foucault cited in Bo-Rygg 2008: 85).

9 To create spontaneously without preparation

Klee used eleven different geometrical elements comparable to the form species of Isomorphology presented in chapter four. He then integrates and recombines them through different works for example *Assyrian Game* (Fig.3)(Verdi 1984: 36). The emergence of different elementary forms in Klee's work are symbolic as signs of nature's growth processes; including radiation, spiral movement or stratification.

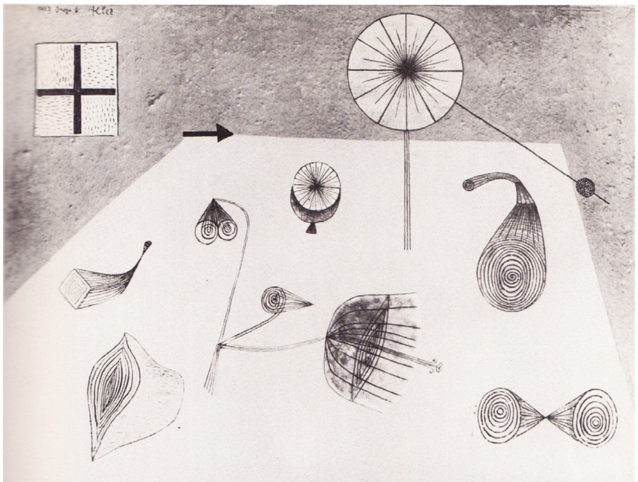


Figure 15.
KLEE, Paul, 1927 Time of the Plants. Pen on paper on cardboard, (c. private collection Rome) from VERDI, Richard. 1984 Klee and Nature. London: Zwemmer.

Klee's work, like Goethe's, reveals an understanding of the leaf as a reflection of the articulation of the whole. Building on this understanding Klee devised diagrams of structural types of leaves and then improvised new types from this understanding (Lynn Henry 1981: 60), saying 'the power of linear radiation produces an individual typology of leaf forms' (Klee as cited in Lynn Henry 1981: 27)(Fig.14). Klee noticed how the invisible 'nature' of the leaf and tree lay in the patterns of development of the stem or trunked branches and full foliage. In discussing leaves, he noted the gathering of energies by drawing bundles of veins at the base of the stem and the linear branching of these veins into typical branching patterns, he then asked his students to create imaginary leaves on the basis of these rules. One student described how Klee paced around the room saying a few words softly with long pauses 'we had to admit that the first thing we had to do was learn to see before we could learn to draw' (Bauhaus student cited by Spiller 1961: 37).

Klee's knowledge of shared forms amongst seemingly unrelated species inspired many poetic comparisons which he made visible and therefore shareable through drawing. Klee's work reveals analogies between the most disparate beings, and creates the impression of having reduced the complex natural world to a subjective semblance of order. At this level the forms of plants and animals can meet, the hidden shapes of crystals, diatoms and protozoa all reveal hidden kinship. These comparisons rely upon the discovery of hidden formal resemblances[10]. For Klee it was not just plants and organic nature that could grow and radiate energy but abstract geometries and signs as well. Klee was inspired by a combination of geometry and nature to create new combinations of forms, which show his liberation from observation.

In 1926, Klee departed further from observation and began to construct his plants out of geometric forms, as in 'Time of the plants' 1927 (Fig.15). In these works Klee made trees out of triangles and squares, fruit out of ovoid's and circles, flowers out of cones and pinwheels. Klee was particularly fascinated by the mathematics of the plant world and, like Galileo who said, Klee seems to have believed that nature is composed in geometric characters: triangles, circles, hexagons etc. This was not a retreat from nature itself, but a penetration into nature's own geometries found in organic structures and the laws of growth and change which can be understood as a move towards nature, not away from it. Nevertheless the work appears more abstract and is often assumed as abstracted or removed from nature. Klee recognized this exchange between the geometric and the generative or metaphysical saying 'the possibilities become numberless and infinitely variable' (Klee as cited in Spiller 1961: 35). Klee transposed the qualities of an instance of nature into a highly simplified type and developed one type or form genetically out of another. The task for Klee was clear: to enjoy the greatest freedom in building a bridge between the world within and the world without – a relationship which Goethe describes poetically in this quote:

> *Seek within yourself, there you will find everything. And you should rejoice if, outside of yourself, you find something in nature, which says yes and amen to everything we find in ourselves. We know of no world except in relation to man, we want no art which is not a likeness of this relationship (Goethe as cited in Haftmann 1954:156).*

10 Klee compared the lines of a tree and the lines of a human body 'the linear principles are similar to those of the human body… I at once put to use in my compositions' and describes how drawing the tree was 'more rewarding than drawing nudes' (Okuda 2008:11). Therefore, it is possible that a tree may have offered Klee greater insight into the human body, through analogy than the human body itself.

Klee, Science and the Bauhaus

Klee's method did not evolve in isolation; he studied widely in the arts and sciences in order to forge this new ground. I will now explore the diversity of Klee's research through specific examples of his practice[11].

During the 1920s and 1930s Klee experimented with ideas from biology, meteorology, astronomy, geology and physics and combined these ideas with basic systems of artistic construction; perspective, geometry and visual use of musical rhythm and melody. An important factor during this time was the great interest at the Bauhaus in the sciences and technology[12]. By 1926 physics, mathematics, mechanics and chemistry were all part of the basic curriculum at the Bauhaus[13].

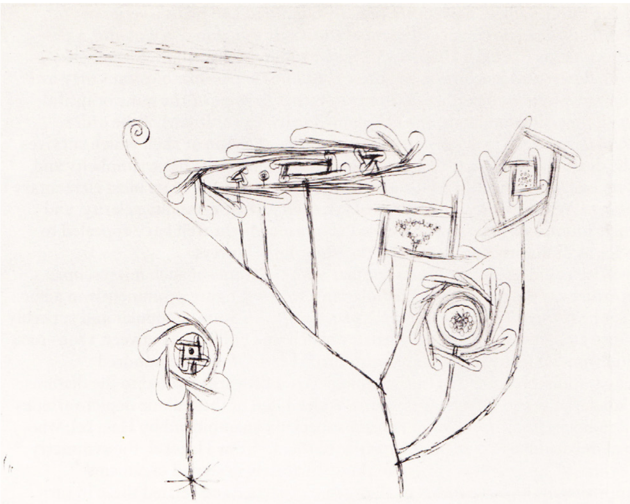


Figure 16.
KLEE, Paul, 1926 Super-culture of Dynamoradiolaren. Pen on paper on cardboard, (Kunstsammlung Nordrhein-Westfalen, Dusseldorf- from VERDI, Richard. 1984 Klee and Nature. London: Zwemmer.i-)

Klee's concepts and images of nature ranged beyond the visible universe to include the invisible: plant anatomy, cell structure, weather patterns, geological strata, cell fertilization/division/growth and the laws of statics and dynamics. Klee's scientific investigations informed his own lectures at the Bauhaus including his 'Principal Order' lecture with sketches of the structure of plants and leaves referred to as 'observational drawings

11 To gain insight into Klee's relationship with science, I draw upon two key works by Sara Lynn Henry: Paul Klee and Modern Science PhD Thesis, 1981, and her later chapter in Biocentrism and Moderism, 2010, 'Klee's Neo-Romanticism: The wages of scientific curiosity'.
12 The basic premise of the Bauhaus was to create new art and design by linking the development of science and technology with those of arts and crafts.
13 Invited speakers included the scientists Hans Driesch, Wilhelm Ostwald and Rudolf Carnap (Galison, 1990) . Albert Einstein was on the governing board of the Bauhaus.

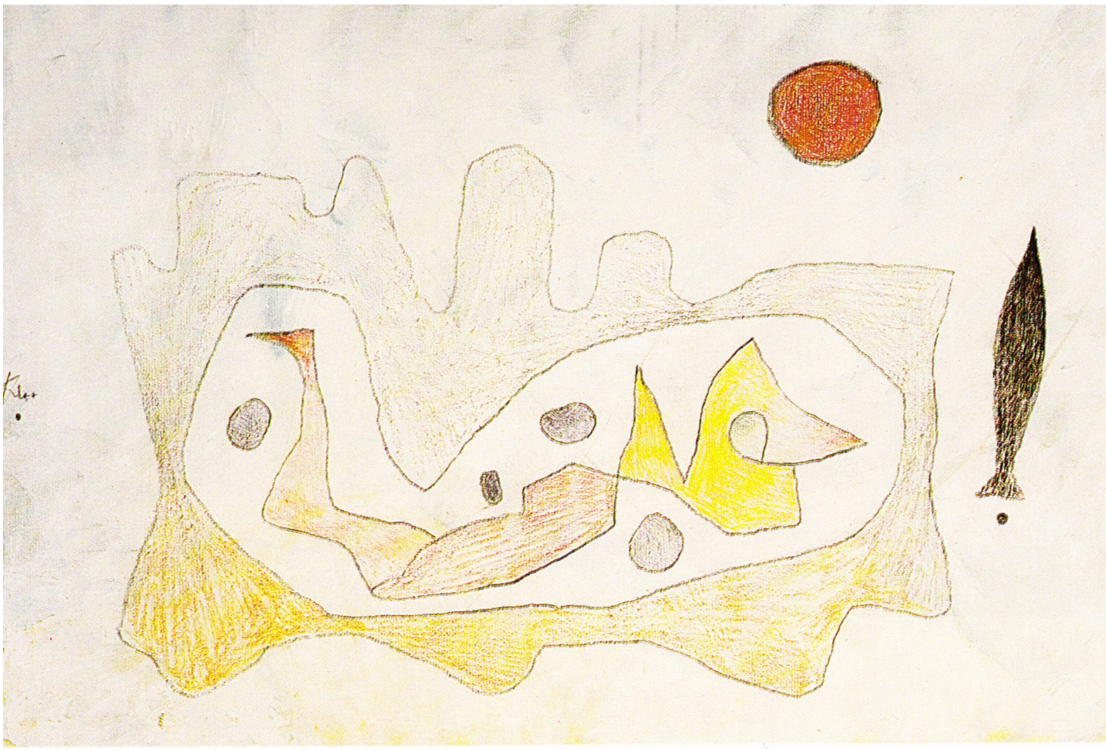


Figure 17.a.
KLEE, Paul, 1917 Ab Ovo. Pen and watercolour on paper on cardboard, (kunstmuseum, bern)(from VERDI, Richard. 1984. Klee and Nature. London: Zwemmer- 78)
Figure 17.b.
KLEE, Paul, 1932 Rock Grave. Pen and watercolour on paper on cardboard, (kunstmuseum, bern)(from VERDI, Richard. 1984. Klee and Nature. London: Zwemmer- 78)

showing the structural energies in leaf and veins' and 'Structural Formation' discussing the most primitive form and rhythms as the repetition of horizontal and vertical lines (1922) (Klee,1961: 35). Teaching affirmed Klee's own practice, as he gained further insight into the nature of his own studies by sharing with others. Beginning with the very basic elements, he taught the building of image forms as geometric shapes and simple colour and tone gradations, which he applied in his own work[14]. He also developed a series of lectures on statics and dynamics in 1924, investigating each formally through various modes of shift, rotation, reflection, movement and counter-movement.
As the outcomes of the scientific investigation of others were fundamental to Klee's artistic achievements, Klee deliberately emphasised the parallels between artistic and scientific analysis of the natural world. Klee believed that for the artist, like the scientist, analytical, even microscopic observation reveals insights into the genesis and structure of objects that are not accessible to the superficial gaze. Drawing analogies between the micro and macrocosm is constant in his thinking and Klee understood the fractal nature of the tree as differentiated into branches, twigs and leaves and these again into stalks veins and leaf tissue 'in this pattern can be found ideas and relationships that form an image in miniature of the pattern of the whole' (Baumgartner 2008: 30). The work 'moving blossoms' was inspired by microscopic animal life and related to the drawings of an imaginary species 'Super-culture dynamoradiolaria' (1926)(Fig.16). Klee was familiar with the rarefied language of the taxonomist and used this knowledge to create science-inspired titles for his works.

One scientist who introduced Klee's generation to the microscopic world was Ernst Haeckel, who made pioneering studies of the marine fauna diatoms and radiolarian. Haeckel was a self confessed disciple of Goethe and extended the Goethean view of nature to encompass microscopic life (Lynn Henry 1981: 55). Klee owned Haeckel's *Art Forms in Nature* (1889-1904) so he would have been familiar with the forms of diatoms and radiolarian.

Klee's embryonic images make clear biological references as in 'Ab Ovo', 1917 (Fig.17.a) and 'Rock Grave' 1932 (Fig. 17.b): 'if such fantastic forms exist under the microscope, why should they not encourage the artist's imagination and freedom?' (Klee in Lynn Henry 1981: 44). The process of cell division is the subject here and re-iterates Klee's emphasis on embryology in his teachings (which came from Haeckel). In these images,

14 Klee taught an advanced course in the fundamentals of form at the Bauhaus in 1921-22.

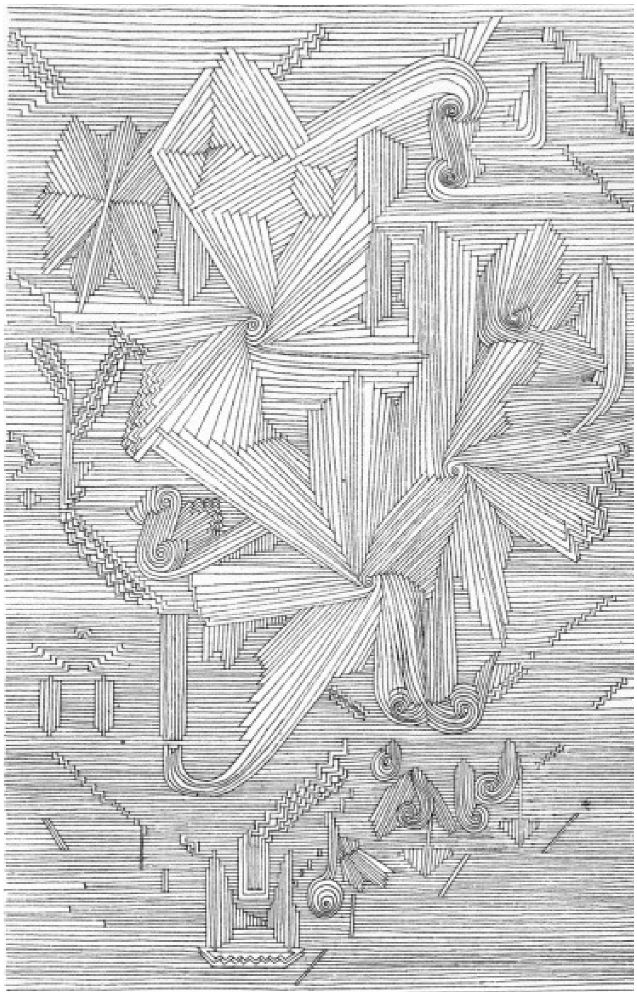
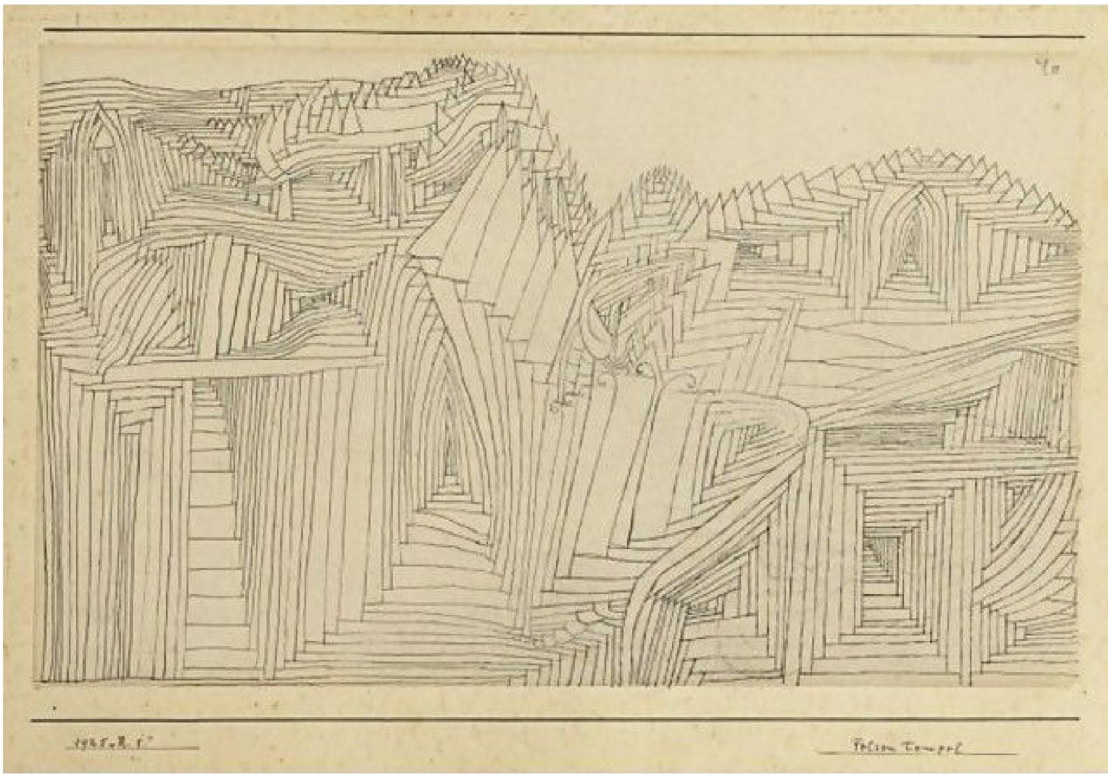


Figure 18.
KLEE, Paul, 1926 Botanical garden, section with the ray leaved plants, (CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum)
Figure 19.
'Rock-cut Temple' 1925 (from http://user.chollian.net/~sarah000/gallery/klee2.html)



the viewer sees inside the egg to a biological foetus[15] with suggestions of internal organs, revealing the influences of biological diagrams and the work of Haeckel. Klee's art went a step further and suggests that the proto-genesis of form could be symbolised by the division of a circle by an arrow (Klee in Lynn Henry 1981: 22). In 'Twins' Klee shows a more sophisticated understanding of cell theory; two cells quiver with protoplasmic energy and their internal structure suggests chromosomes surrounded by cytoplasm and with a pencil line indicating the cell wall. Klee applied his knowledge of cell division in the work 'Genesis and natural division of the cube' where even pure geometry can be subject to organic processes.

Figure 20.
KLEE, Paul, 1926 Olympus in ruin. Pen and watercolour on paper on cardboard. from Huggler, M. 1965 Drawings of Paul Klee. Borden Pub Co.

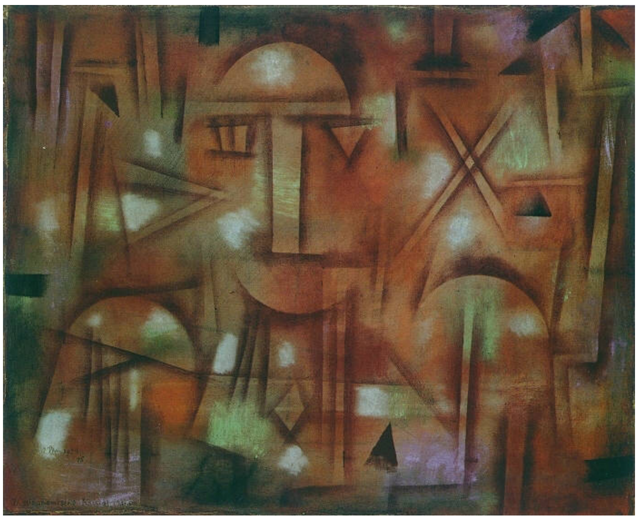


Figure 21.
KLEE, Paul, 1924 Physiognomic Crystallisation. Pen and watercolour on paper on cardboard (from http://user.chollian.net/~sarah000/gallery/klee2.html)

15 Leonardo da Vinci was the first artist to draw the foetus (1510-1513)

Klee and Geology

Another subject of investigation for Klee was Geology. He had been experimenting with strata structure in his landscapes since 1920 and the interweaving of strata and growth patterns resulted in 'Botanical gardens', 1926 (Fig.18) where the organic and tectonic merge. Klee used his knowledge of the structure and life of rocks on a macro scale to improvise on a micro scale. He drew cliffs as progressive forms of growth and individual rocks from constructed crystalline forms suggestive of internal and external structure, as in 'Rock-cut Temple' 1925 (Fig.19), in which an internal living structure is evoked by a cut away view, 'like a vital geological diagram' (Lynn Henry 1981: 151). Klee began with regular horizontal divisions interrupted by a few vertical, diagonal and curved lines, suggesting intruding plateaus.

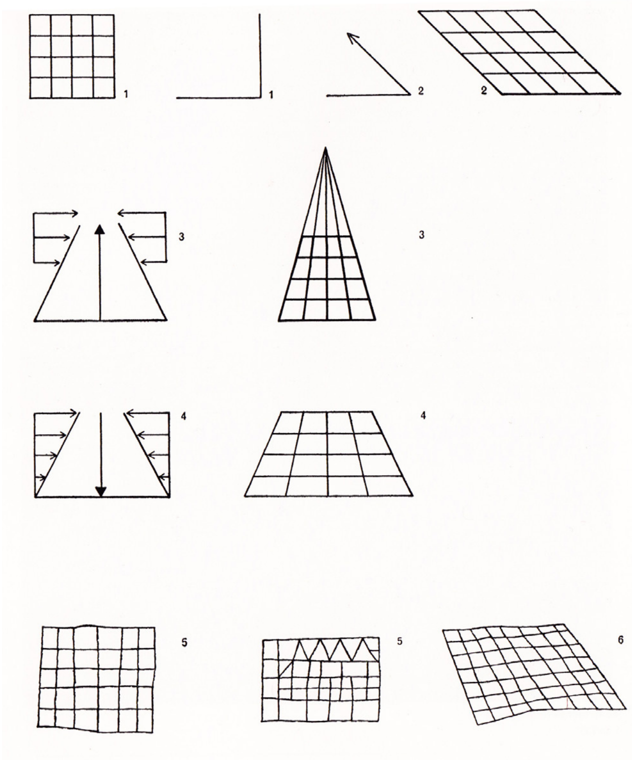


Figure 22.
KLEE, Paul, 1922 Analysis of movement. Pen on paper (diagrams in notebooks volume one), KLEE, Paul. 1961 The Thinking Eye: The Notebooks of Paul Klee. London Lund: New York : Humphries ; Wittenborn. page 234

Klee also drew simple diagrams of parallel lines to stand for strata and arrows to indicate the forces that cause these layers. These diagrams fed directly into his work 'Olympus in Ruin' (1926)(Fig.20), where Klee builds the forms out of abstract pictorial units similar to the geological diagrams of natural science books. Klee began to explore quartz and amber from his own collections and learned the basic geometry of crystal types from Otto Lehmann's 'Die Neue Welt der Flussigen Kristalle' (The New World of Fluid Crystals)(Wünsche, 2011:19). The influence of crystal structures can be seen in 'Physiognomic crystallization' (1924)(Fig.21) which, rather than representing crystal structures as perfectly symmetrical, manifest the irregularities and asymmetries which can be found in nature and art (1930).

Twentieth Century influences

While Goethe was a significant historical influence on Klee, it is important to also note the significant influence of Goethe on the work of Klee's contemporaries, in particular the artist Karl Blossfeldt, artist and scientist Ernst Haeckel and biologist and mathematic ian, D'Arcy Wentworth Thompson.

In 1928 Klee gave his father a copy of the first edition of Karl Blossfeldts' *Art Forms in Nature* and in 1929 Kandinsky gave Klee his own personal copy. Walter Benjamin relates Blossfeldt, Klee and Kandinsky in his review of this book: 'New painters such as Klee and Kandinsky have long been concerned with acquainting us with those realms that the microscope would roughly and violently transport us to, we encounter in these enlarged plants 'stylistic forms' that are more vegetable like' (Benjamin in Okuda 2008:17). The influence of this book can be seen particularly in the individual portraits of various parts of plants that he made between 1929 and 1934, a series that began the same year that the Bauhaus held an exhibition of Botanical Photographs by Blossfeldt, 'Archetypal Forms of Art'.

Although the influence of the pioneering biomathematician D'Arcy Wentworth Thompson on Klee is not evident in the literature, I see a clear link between their work. Thompson realised that forms mathematically alike could belong to organisms biologically remote (Verdi 1984:229) and that nature repeats its basic forms throughout the entire range of its creations. Thompson discovered a number of physical reasons why certain forms are possible in nature, which he presented in '*On Growth and Form*' (1917)(Verdi 1984:229). Klee was also familiar with Theodore Andrea Cook's Curves of Life[16] (1914). Klee's gridded structures as in 'Analysis of movement', (1932) (Fig.22) transformed structure and motion into a periodic yet living system and are therefore close to Thompson's transformation diagrams, and show the basic type forms of nature, such as the spiral and hexagon using graphs and mathematical formulae. Klee shared Thompson's interest in how honeycomb structures arise but approached the

16 *The Curves of Life* portrays the significance of the spiral in 426 illustrations. Through an exploration of the spiral in nature, science and art, Cook open's a discussion on the essence of beauty and human responses to this theme.

questions with different methods and motivations. Thompson believed it could be quick and easy to extrapolate the dynamic of an object from its basic structure. As Klee became more interested in three-dimensional modulations of changing topography, he devised a method of rhythmically distorting an abstract grid to simulate topographical configurations[17].

Klee's discussion of motion is found in his 1924 lecture on 'Pictorial Mechanics[18]' Klee's understanding that the dynamic is the normal state was very unusual. He described 'statics' to his students not as the 'unmoving' but rather as movement brought into equilibrium, as 'the study of the equilibrium of forces' (Spiller 1973:17).

The chapter 'In Klee's enchanted garden' (Verdi, 1984) explores a number of philosophical perspectives on Klee's work. Particularly interesting is the idea of an aesthetic forming of the self which relates to Foucault, who formulated an 'aesthetics of existence' and used Baudelaire and Manet as examples of artists who worked on themselves through their art. Klee said 'I am my style', implying that his work and his self where forming simultaneously (Bo-Rygg 2008:86).

Comparing artistic process to a kind of 'birthing' is a theme in Merleau-Ponty's phenomenology, which aims to encounter the world in a 'pre-conceptual' way (Merleau-Ponty, 1996). Merleau-Ponty's phenomenology shares much with Goethe's philosophy, therefore it is not surprising that Merleau-Ponty thinks about Klee within this philosophical framework. While discussing Klee's work, Merleau-Ponty states 'the line is the blueprint of the genesis of things [...] with Klee, painting is a kind of philosophy, the grasping of the genesis of things'. Merleau-Ponty believed that art can only present something when it 'shows how things come into being, and how the world becomes the world' (Bo-Rygg 2008:88). Merleau-Ponty's view relates to Deleuze and Guattarri's belief that art is a form of thinking, a composite of percepts and affects (Bo-Rygg 2008:88). As Klee's work developed, objects themselves no longer mattered, only his reactions to them, until his attitude to the colours in his paint box became more important than studying nature.

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17 He also experimented with the pantograph drawing tool and used the grid as metaphor for the atmosphere itself, for example in the work 'lightning flash' (1940).

18 While Klee was working on his 'pictorial dynamics', the futurists were formulating new ideas which broke down traditional categories of time, space and perception and which came to Munich through an exhibition and manifesto in 1912. In 1913 Klee experimented with cubofuturist form.

Art as visual analogy to nature's creative processes

At the heart of Klee's thinking was an intuition that pure form could be animated with a life of its own[19]. Through drawing, form could come into being, grow, divide, combine and even reach its own demise, therefore visual problems and natural problems became analogous. The three-dimensional space of the cell and the two-dimensional space of the page, paralleled one another in process. Every step in image making is abstract and dynamic, providing the scaffolding (the simplicity of structure which mass can build around) around which the image is formed genetically (the linear energy gives direction and a guide to the creativity/chaos). The analogy with nature seemed to be real for Klee, as nature permeated his consciousness to the point that he grew a world within, as logical and real to him as the natural world without.

Figure 23.
KLEE, Paul, 1938 Growth stirs. Coloured paste on paper and cardboard, 33/32.4x48.7cm, private collection , Switzerland (Baumgartner, M. 2008) In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum, (p.189)

19 This could be also be explored in relation to Jennifer Mundy's PhD thesis on 'Biomorphism' (1986) which discusses Odilon Redon and Kupka's work with microscopes to further their knowledge of natural form.

> *I place myself at the remote starting point of creation, whence I state a priori formulas for men, beasts, plants, stones and the elements and for all the whirling forces (Klee, 1923:7).*

With this statement Klee was rejecting his previous direct perceptual relationship with nature, commonly perceived as representative/figurative and adopting a more analogous/metaphorical abstract one, where concepts of metamorphosis and genesis were central. He aimed to place nature at the service of his imagination and to find a visual language that paralleled and simulated rather than duplicated nature's creative processes. This shift in Klee's work (which is an experience I share in my own work) proved a liberation. No longer tied to the representation of objects in nature, but instead to a genuine re-creation of them through his art, re-building an intelligible world: 'an in-between world, another possible nature, which intends creation, causes what is not to become visible, yet without falling into the subjective imagination's service' (Klee cited in Lynn Henry 1981:92). Klee's visual analogies of nature are sites (locations of artistic production) where the intelligence of the artist resonates with the living processes of nature, which he described as 'a new naturalness, the naturalness of the work' (Klee cited in Lynn Henry 1981:148).

The analogy of the seed is central to Klee's broader concerns with the process of germination in both nature and art, he says 'despite its primitive smallness the seed is an energy center charged to the highest degree' (Lynn Henry 1981: 65). Just as the seed was charged, or connected to the point by the line of the shoot so too was the artist charged by 'his own form creating energies' to create lines (ref methodology on line and drawing). Klee's interest in the parallel aspects of artistic creation and creation in nature is clear in his teachings at the Bauhaus from 1921. In drawing, he saw the starting point of creation as the passive dot. When the dot moved, it became a line, which in turn became a surface. Therefore movement was central to Klee's thinking: 'movement is the basis of all becoming, the eye follows the path prepared for it through the work, itself recorded movement, received as movement' (Haftmann 1954: 69). In nature Klee saw the starting point as the seed from which emerged a shoot and developed into a stalk with leaves, after this came a flower and then the fruit or seed again (Moe 2008:56). In 'Growth Stirs' (1938)(Fig.23) Klee's marks are suggestive of embryonic elements, which he evolves into his own visual language. The marks can be interpreted as the germ cells of art rather than of science.

Klee used analogies and metaphors to think about his work and himself, 'my little plant of a soul will soon be able to strike new roots again' (Verdi 1984:10) and it is precisely this analogical thinking that made Klee's work so moving. Klee also described himself as the crystalline type. Lyonel Feininger also compare Klee to a plant, 'his method of working can really be compared to the organic development of a plant'. (Lyonel Feininger 'Recollections of Paul Klee' 1945). Theodor Daubler also compares Klee to a plant after his time in Tunisia in 1914 'the plant shot up at once. Now it is putting forth flowers' (Okuda 2008:13), speaking of his fiery watercolours implying that 'when Klee draws, new roots sprout forth; and colourful flowers emerge when he paints'(ibid).

'Art relates to creation in the manner of a metaphor. It is always a model, in the same way that the earth is a model for the cosmos' (Okuda 2008:14), this relates to Goethe's outlook 'Art is parallel to creation: sometimes it is a sample, just as earth is a sample of the cosmos' (Goethe cited in Haftmann 1954:150). This metaphorical level of understanding helped Klee to develop his micro/macro comparative repertoire of plant themes and images.

Amongst Klee's models for a formal cosmos or 'little worlds' is the 'blossoming apple tree, its roots, its rising sap, its trunk, its construction, its sexual function, the fruit, its core and seeds. A system of conditions for growth' (Okuda 2008:14). Klee takes the tree[20] as analogy for the artist - the medium is the trunk, the works are the fruits. The tree became an analogy for the macro and the microcosm 'precise analogies for the laws which govern the existence are repeated in the smallest, outermost leaves'(Haftmann 1954:122).

With Klee, it is also possible to make the comparison between the artist and the gardener[21], carefully selecting and tending to creative processes of growth, tending to aspects within conditions of artistic weather and inspiration to cultivate something wonderful. When a plant produces a fruit it is the sign of the success of previous stages of its development – equally, the artist is a historical being, bearing artistic fruits grown from time and experience, a creative achievement parallel to those of a gardener. Klee believed in letting things grow of their own accord, which was reflected as he patiently waited until the creative image formed within (Haftmann 1954:154).

20 Mathematician Alessio Corti and I also found the tree helpful as a metaphor when drawing in the fourth spatial dimension as discussed in the next chapter.

21 A comparison that William Latham also makes in *The Conquest of Form* (Latham, 1990)

Towards a developmental morphology

Although there is no reference to the concept of 'ontogeny' in Klee's writings or in the literature on his work, he does talk about development. The concept of ontogeny, as outlined by morphologist Norman MacLeod as 'the conceptual and physical development of parts and the development of existing and known structures through actions which change the proportions and in the end create something new' (MacLeod, 2014, personal communication) is a useful tool for interpreting a selection of Klee's works in Tate Modern's exhibition. The biological concept of ontogeny and the new science of embryology were emerging in Klee's time through Haeckel (using images as arguments) but ontogeny is now better understood in contemporary zoology and means a developmental sequence, for example the development of a human embryo to an adult. This repetition of forms with slight variation in a connected series becomes an analogue for the evolution of organisms and artworks.

In 'Fishes' (Fig.4.c.) the progression of form takes place within the body of the fish itself, suggesting time, movement and growth simultaneously. Klee was attracted to the underwater world of fishes because of their freedom of movement (in any direction, whereas humans are much more restricted). The 'fishiness' of the fish is maintained through the transformations; each stage bears a unique gradation of colour, repetition of the same form at different angles and scales, moving forwards, backwards and sideways creating a feeling of emergence from a dark background. Klee's watercolour washes elevate the forms to a resonant poetry. The fish appear transparent, we see the traces of their development through a clear membrane, like a cell, representing Klee's penetration of form beyond surface appearances. In these works Klee, like the fish, allows for many perspectives; above, below and alongside the forms.

Next to Fishes (fig.4.a) is 'Growth of the night plants' which can be read as an abstract ontogenetic series. The abstraction in this work is not from observation, but from an insight in to the growth of plants from thought and experience itself. In 'Pottery' (Fig.4.e.), the circle is analogous to the embryo which, through a series of transformations, becomes a jug (adult). This occurs through a progression of forms, grading from white to black through pale pink, pink, deep pink, purple, grey purple, grey and black. 'Suspended Plants', 1921, (Fig.4.a.) is another work representing growth in the abstract. The transformation from triangle to square, through the repetition of forms with slight variation, becomes an analogue for evolution as descent with variation, while echoes of form grade through shadows and colours in other directions and other aesthetic dimensions. Klee's expansive way led to the dimensional promotion (or

Figure 24.
KLEE, Paul, 1926 In view of a mountain shrine. Pen on paper (book details) from Huggler, M. 1965 Drawings of Paul Klee. Borden Pub Co.

inversely, de-motion) of his work from 3D-2D to 4D(time)-2D. In this interpretation of Klee's work as an ontogenetic series, I am mapping this biological concept onto artistic practice.

Klee's artistic work brings qualities and dimensions which reach beyond the purely biological. These works can also be interpreted through the conceptual tools of music: as a musical fugue, interpreting each shape as a different voice, each meandering through nature's basic patterns; a polyphonic progression in time and space. 'Komodie' (Fig.5) is set on horizontal lines on the page like musical bars, rhythmic in line punctuated by solid notes of chequerboard, diamond and rectangular patterns, rhythms, melodies. What better analogy for music than to attempt to visualise, simulate/re-create the metamorphosis and rhythm of life itself? This representation of nature developing through periodic stages, abstracted through repeated and generalised shapes, is set into motion by progressive colour and tone gradations. In 'View of a Mountain Shrine' (1926) (Fig.24) Klee creates a sense of growth through the repetition of the form, and in the work 'Omega 5 (traps)' (1927) – the repetition of forms is similar to the Isomorphology form range.

The image becomes a visual chronicle, incorporating evidence of its own development as the layering of form and colour create a sense of form travelling through time and space. In this combination of artistic, biological and periodic nature we learn to see the growth and developmental process through a simultaneous visualisation of multiple dimensions, thus, the artwork as visual chronicle.

> *Art plays an unwitting game with ultimate things and yet it reaches them (Klee in Verdi 1984:9).*

First Klee studied the static forms of nature and of the pictorial space and later he set these forms into motion to visualise genesis and growth. Klee even arranged his teachings to emphasise first the statics and then the dynamics of each topic, although the categories were never mutually exclusive (Lynn Henry, 1981:43). Similarly, in biology there is the study of structure at rest – anatomy, and the study of functions – physiology, genetics of heredity and evolution. Even Klee's attitude to his work resonates with the process of evolution: 'You will never achieve anything unless you work towards it. You can break in halfway through the process, and least of all start with any result. You must start at the beginning. Then you will avoid all trace of artificiality, and the creative process will function without interruption[22]' (Haftmann 1954: 30). One of the foundations of Klee's teaching was that no artist, and much less the student, should rely on ready-made forms, but start at the beginning, in order to build.

Conclusion

That such a visual equivalent to Goethe's theories should only have come into being a century after his death is understandable when we remember that the artistic conventions of Goethe's day were still prioritising the outward appearance of things. Goethe was aware that even the most painstaking representation of the resemblance of things was not nature itself. At a different time and in a different place, Klee was aiming to uncover the 'nature of nature', through viewing and studying nature's inner life, its processes and its dynamics; 'A form should retain the footprints of its dynamic development' (Klee 1920:2). Klee's artistic approach made this dynamic development visible.

22 This could relate as much to development as to evolution in a Darwinian sense.

Klee was aware that 19th century biology had discovered that each step of the evolutionary ladder was a variation of the one before and he realised that if the forms of nature had been different in the past, they could be different again in the future: 'different forms may well have arisen on other stars, in its present form, this is not the only world possible' (Lynn Henry 1981:10). Klee embarked on a systematic study of the world around him, and believed in the potential of human creativity 'the future slumbers in human beings and needs only to be awakened'(Verdi 1984:7). 'That Klee was an accomplished natural scientist has long been acknowledged' (ibid). Klee was always a scientist in the service of art and has been described as 'the true forerunner of the surrealist approach to natural history' by Rene Crevel (Baumgartner 2008: 41-42) because of his distortions and deformations of the natural world in the stage-like space of the pictorial plane.

What was new in Klee's work was a result of the impact of modern science and of his willingness to represent the phenomena themselves, working towards a dynamic representation of nature. Klee's work rendered visible, and interpreted, the invisible processes of natural form, and therefore made these visible to others, opening minds and making life larger than it usually appears. In Klee's universe 'everything is a dynamic nature; static problems make their appearance only at certain parts of the universe in edifices, on the crust of the various cosmic bodies [...] there is a microscopic dynamic and a macroscopic dynamic, between them stands a static exception: human existence and its forms'. (Lynn Henry 1981:90)

Although Klee's science was in the service of art, his ability to visualise the dynamic nature of form was ahead of the scientific visualisations of his time. Understanding Klee's work as analogous to ontogeny, and therefore evolution, makes the potential of Klee's methods very exciting. Klee's artistic research employed the methods of drawing and watercolour, bringing a qualitative and unique aesthetic to morphology, to re-create the dynamic nature of nature. In the 21st century, we are still a long way from successfully representing nature as a dynamic reality – as process. Popular culture still has tendency towards object based thinking, but there has been a shift since the 1980's (postmodernism) in how we understand human identity (physically and conceptually) as entirely mutable rather than as fixed. The need for representation and insight in to the dynamic nature of the natural world is reflected in the emerging field of 'process biology' (Dupré, Exeter). We live in a moving present and changing objects cannot exist in a fixed state – such that it is possible to argue that there are no objects. Like Klee, I endeavour to move closer to the dynamic nature of nature through art and find it helpful to think of a plant as an instance or slice of reality, and rather than represent this slice I aim to represent this slice within a continuum, as 'life represented alive'.

I believe that with Klee's works as inspiration, and through my own variations on his methods, as informed by contemporary biology, a move towards a more dynamic representation of nature and even towards a visual simulation of nature's processes is possible. This anticipated artistic practice, brings the combination of insight, imagination and intuition that Goethe believed was so complementary to science. The next chapters 'Notes from an artistic collaboration' and 'Isomorphogenesis*:* drawing a dynamic morphology' will reveal the development of the Isomorphology study and the Goethe inspired drawing method, drawing from art and from science towards a dynamic representation of nature, itself a process, in constant formation, without end.

Chapter Seven

Mathematics and Art: Notes from an Artistic Collaboration

This short chapter, 'Mathematics and Art: notes from an artistic collaboration' was published as a book chapter in Imagine Maths Four (Anderson and Corti, 2015) and gives substance to the conceptual link between my work with Klee's colour gradation and the subsequent application of this method in the following chapter on 'Isomorphogenesis'. It was written at a time when I was developing these ideas and it reveals a process through which I made a departure from drawing the more observable to the more conceptual.

While working on the Klee chapter, before developing the Isomorphogenesis method, I proposed to mathematician Alessio Corti (Imperial College) to draw a tree in the fourth spatial dimension as I hoped this process would inform my approach to represent form as dynamic and temporal. This chapter explores the concepts of development as related to both biological and abstract, mathematical form. It combines a first and third person perspective.

1. Introduction (Gemma and Alessio)

Alessio is a mathematician working in algebraic geometry. Gemma is a visual artist and lecturer of drawing. We have been collaborating for some time on different projects. The collaboration is still ongoing. For instance, we delivered two workshops[1 2] on drawing in 4 dimensions (4d) for the general public.

In this chapter, we focus on a recent project on drawing trees in 4d as an example to show how our projects begin, evolve and eventually find their way into art. We also give you a feeling for the kind of experience we are planning for these workshops. In section 2, written in the first person by Alessio, we show how to draw 4d trees. Section 3, written in the first person by Gemma, reflects on how this material finds its way in her art. The concluding Section 4 is written again, as this introduction, by both authors.

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1 http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/

2 The first at Falmouth School of Art Drawing Symposium, 23[RD] April 2015, and the second at The Cornwall Morphology and Drawing Centre, 25[th] April, 2015 (see chapter nine for details and a discussion).

2. How to draw 4d trees (Alessio)

While we were working on the paper Drawing in Mathematics: From Inverse Vision to the Liberation of Form, I showed Gemma some drawings I did as a teenager of polytopes in 4d. For instance, Fig.3 (see page 69) shows one of a series of drawings of the inside of a 120-cell. As an artist, Gemma wanted to be able to imagine and draw in 4d and started a conversation with me about this. She drew a 4d cube folding from a 3d net and then some of the 6 Platonic solids in 4d. I was not very interested in pursuing this further as it has been done before.

Then, after some time, Gemma came asking about drawing a 4d tree. She was inspired by her naturalistic interests to imagine a possible natural world in 4 spatial dimensions. I was laughing, it seemed a bit of nonsense, I did not know if it was possible. I thought about it. I decided that a tree is a manifold with a height function on it, as in Fig. 3, a bit limited perhaps, but maybe interesting enough to be worth pursuing further. So when we think of an ordinary 3d tree, for example, we are just thinking of the outside surface, the bark-matter of the tree. So a 4d tree is a 3d manifold with height-function.

It is important to understand that I did not want to be tied to the image of a literal tree, and we soon had several metaphors going: the Universe with its matter density function is the bark of a 4d tree: the roots of this tree are in empty space and the upper branches and fruits are the stars, planets and black holes. So by drawing 4d trees we are also learning to draw the possible shape of the Universe.

Gemma also works with biologists and is interested in the act of drawing as an analogy to the development of an organism. She proposed another metaphor: if the height function is time, then the different time slices are like photographs of an object taken in a time sequence like when viewing an developmental series. I had not seen a biological developmental series before, and I then said that a developmental series for the history of the Universe in time would be a 5d tree.

'Suspended Plants', is a watercolour by Klee: the gradation of colour and form suggest that we are seeing the slices of an abstract developmental series. To take this further, we started a conversation-in-drawing, where we would draw each other questions, free associations, possible answers. In Fig.3 we started exploring ordinary trees in 3d. You notice that to make things more interesting we allow branches to come together, which they don't do (or very rarely do) in real life. We started looking at slices of the height function: generic slices and special slices where branching happens. To make our

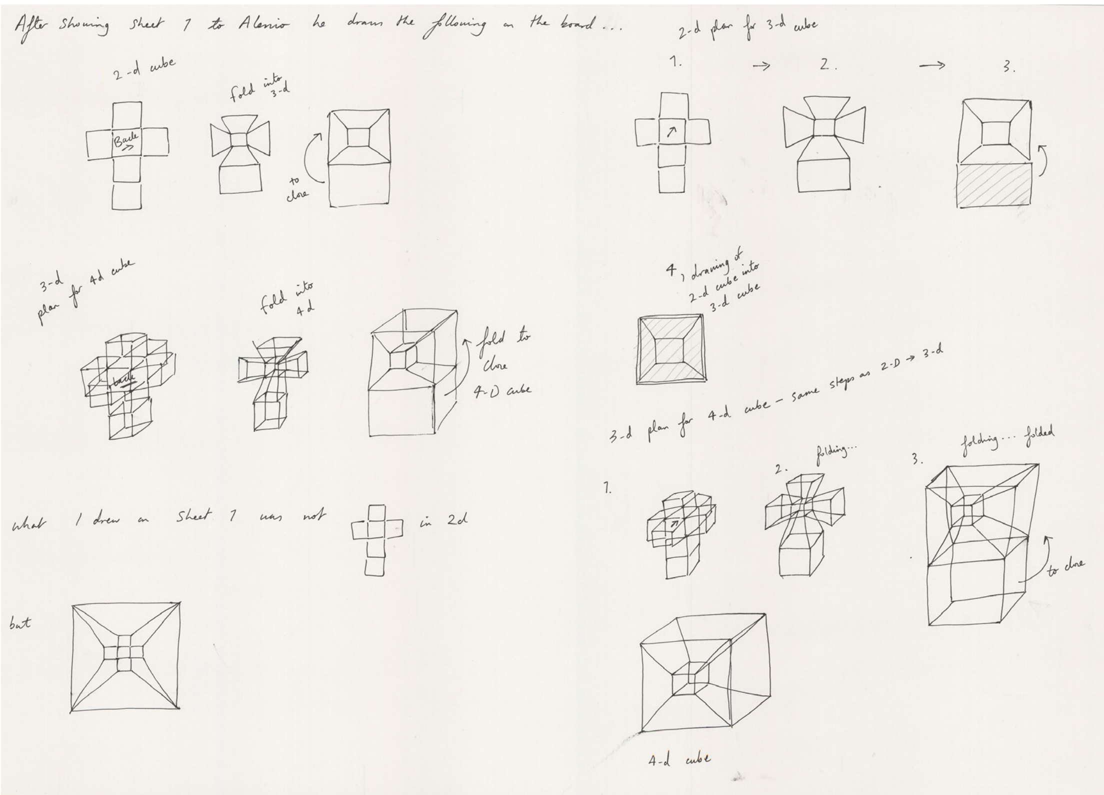


Figure 1.
ANDERSON, Gemma, 2013. Hypercube, pen on paper.

life simpler, we decided to assume at most one new branch at any given height. We learned how the tree is made of disks and pants, one of either piece (a disk or a pant) for each special height. Then we learned how to make a tree from an instruction sheet and a collection of disks and pants. You can see the instruction sheet on the upper right corner: it is a drawing made of I & Y (and upside-down Y): it tells us where to glue the disks and pants.

We found that there is a precise analogy between deconstructing a particular tree into disks and pants and then using disks and pants to build an arbitrary tree and Gemma's own blow-up or creative morphology drawing method, which she has been teaching in workshops with artists and scientists, where an object is observed; described; drawn; memorised; deconstructed; and creatively recombined.

To draw 4d trees, we now need to promote all these concepts and drawings up one dimension, as illustrated in Fig. 4.

Here you see two tables. The left table is the list of the concepts we used to draw 3d trees. A tree is a connected surface with a height function on it; a generic slice is a disconnected 1d manifold: a collection of disjoint circles; a special slice is a 1d object with just 1 singularity; the pieces are disks and pants: these are certain 2d surfaces with boundary; the instruction sheet is a drawing made of I & Y. The right table is the list of the concepts that we need to develop for drawing 4d trees. A tree is a connected 3-manifold with height; a generic slice is a disconnected surface: a collection of surfaces of different genera (a doughnut with many holes; the genus is the number of holes); a special slice therefore would be a 2d object with one singularity, the locus where branching occurs; the pieces then would be certain 3d manifolds with boundary; and what would the instruction sheet be? In Fig.5 we learn how a surface of genus g crossing a special height acquires one singular point. This happens by tightening a curve on the surface until it becomes a single point. There are two types of curves: those that split the surface it two disconnected halves, and those that don't. In the first case a surface of genus g is split into two surfaces of genus g1, g2 with g1+g2=g; in the second case a surface of genus g "loses one hole" and becomes a surfaces of genus g-1. Fig.8 pieces: a surface of genus 2 crosses a special value and becomes a surface of genus 1; a surface of genus 2 crosses a special value and splits into two surfaces of genus 1. Imagine the surface of genus 2 to be solid & filled with red "bark-substance", and the two surfaces of genus 1 being "drilled out" of it from the inside. We can imagine gradation in the red as we move up the tree. Now we have everything that we need to draw 4d trees.

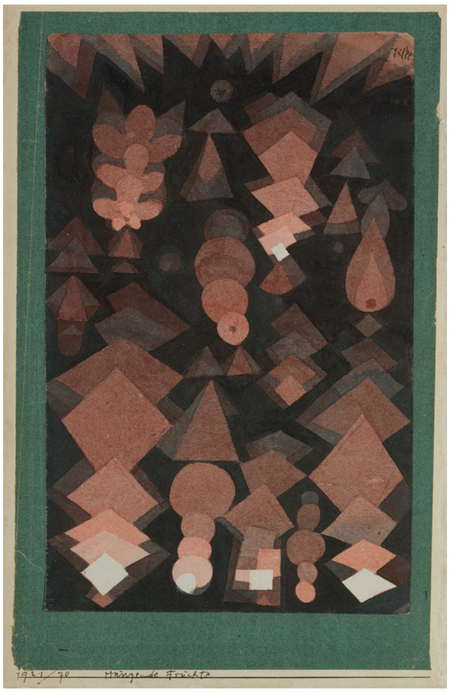
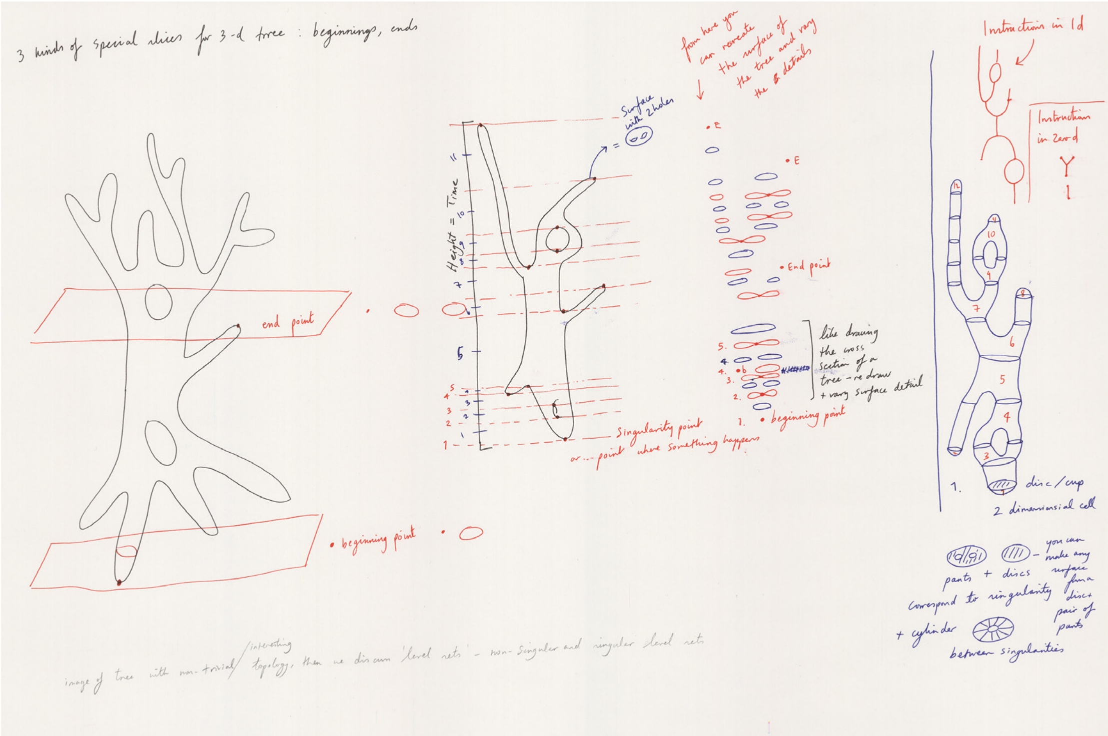


Figure 2.
KLEE, Paul 1921. Suspended Plants, watercolour on pulpboard 22.9 x 30.9cm. CANTZ, Hatje. (ed.) 2008 In Paul Klee's Enchanted Garden. Berne, Switzerland: Klee Zentrum.



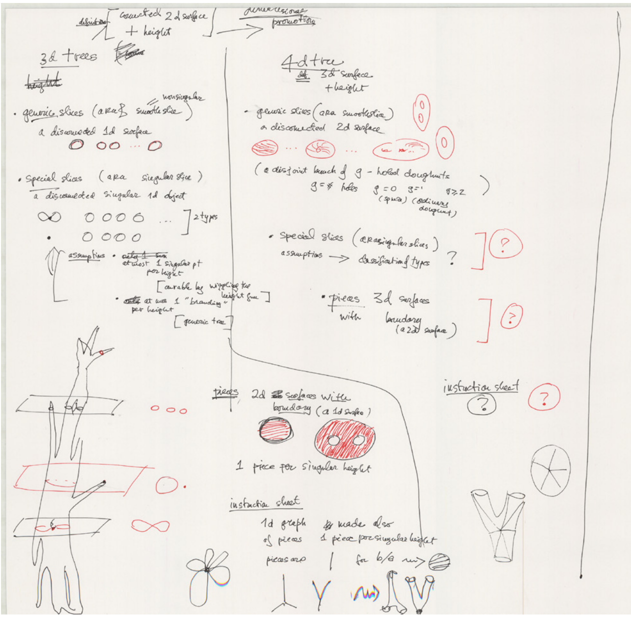


Figure 3.
ANDERSON, Gemma, 2013. Drawing of morse theory of normal tree. Pen on paper.

Figure 4.
ANDERSON, Gemma, 2013. Dimensional Promotion, Pen on paper.

3. Art (Gemma)

This drawing (Fig. 7) shows a drawing of a 4d tree. It is drawn from an instruction sheet that we made up. The numbers on the instruction sheet are the genera of the surfaces occurring in the corresponding slice. The drawing shows the pieces: you have to imagine that, to make the tree, the blue part of one piece is glued to the red part of the higher piece and so on. The grey shading represents the bark-matter of the tree. In the next drawing Fig.8 the grey lines signify where the blue surface attaches to the red surface to form a slice of the tree. On the right hand side I am thinking of the gradation of color as the height function increases or decreases. In the drawing in Fig.9 I am thinking more about the topology of the slices. On the left I am experimenting with topologically equivalent ways to draw a slice. On the right I am writing myself instructions about the gradation of colour. This makes me think of Klee, and in particular the following quote:

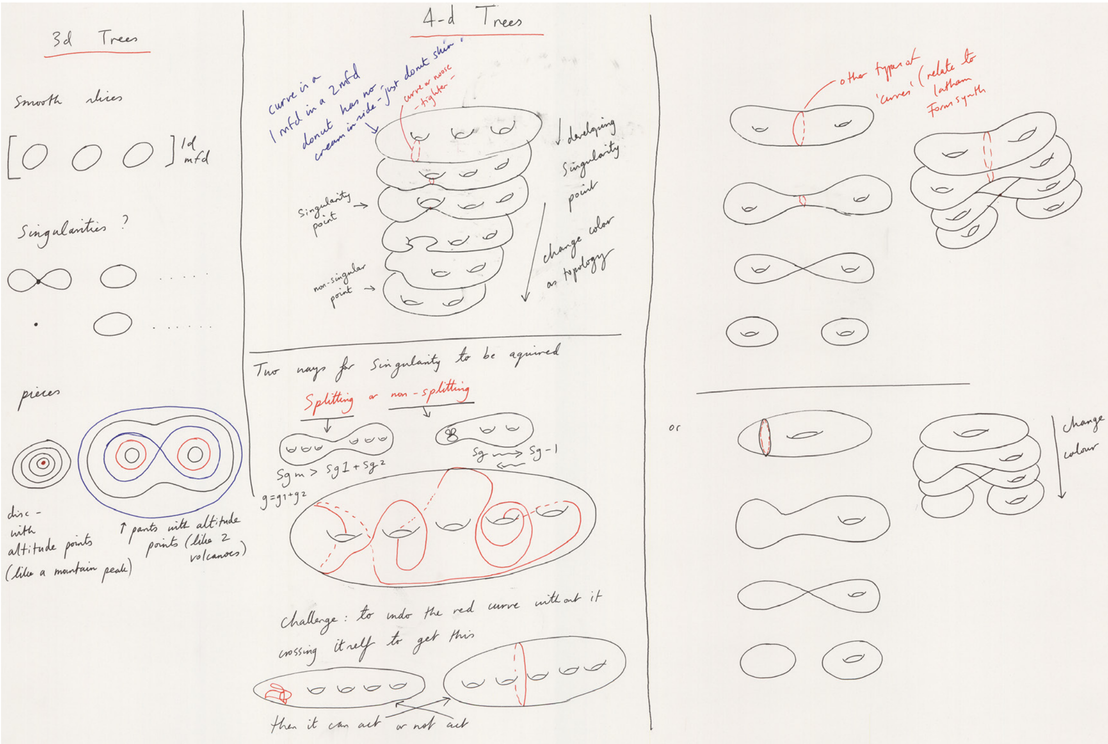
> I was able to free myself from all that was accidental in this slice of 'Nature,' both in the drawing and in the tonality, and rendered only the 'typical' through carefully planned, formal genesis (Gockel, 2008)

4. Conclusion (Gemma and Alessio)

We have shown you slices of the Morse theory of our conversations. Drawing is our shared language. We start with the kind of question that drawing generates: how to draw 4-dimensional trees. The conversation develops with free drawing-associations that we each take out of our own professional practice. At the beginning we leave applications aside and we keep our willingness to explore the topic together. Later we may find applications: for instance we now think of using this material for a public workshop; in a different application, our drawings find a way in Gemma's art (Fig. 10 and 11).

Early in his career as a mathematician Alessio was not interested in discussing his work with non-mathematicians. He is one of those trees whose roots are up in the sky and whose direction of growth is down, towards the ground. Recently, he became interested in giving mathematical objects a material body: with this project, he feels that he has grown a new branch in the Earth.

In conclusion, Gemma would like to reflect on a quote from Goethe that has been important to her for a long time, which expresses her motivation as an artist. It came as a surprise to her that it fits so well with the work that we have discussed in this paper:



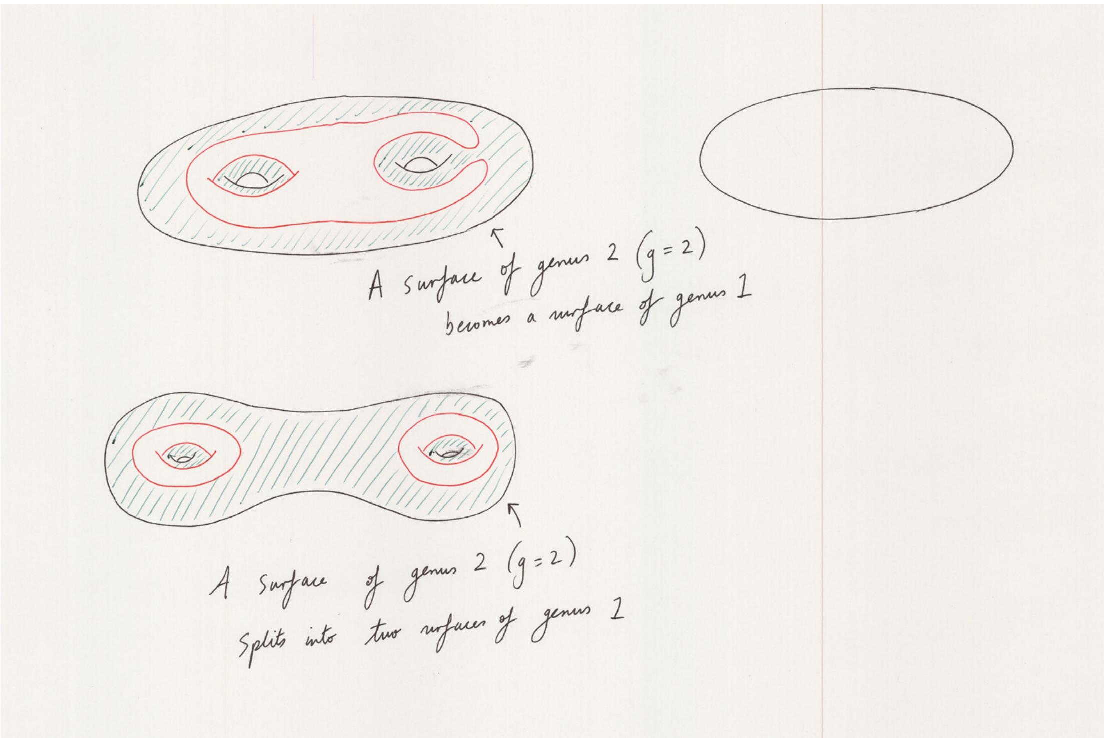


Figure 5. (top)
ANDERSON, Gemma, 2013. Technicalities, Pen on paper.

Figure 6.
ANDERSON, Gemma, 2013. Pieces: a surface of genus 2 crosses a special value and becomes a surface of genus 1; a surface of genus 2 crosses a special value and splits into two surfaces of genus 1. Pen on paper.

> The original plant [Urpflanze] is becoming the most wondrous creature in the world, one for which Nature herself should envy me. With this model, and with the key to it, one can now invent an eternity of plants, which...even though they don't exist, yet could exist and are not merely painterly or visual shadows and appearances, but carry an inner truth and necessity (Goethe, trans. W. H. Auden and Elizabeth Mayer 1970: 310-11).

This project gave Gemma some tools that helped her to take a fundamental step in her work away from strictly naturalistic observation. This move away from the observation of nature as the starting point for creating artwork is not a matter of scale (i.e. going from micro to macro) but instead of style of thought and observation.

After this project, Gemma saw the possibility of creating work from a kind of drawing algorithm involving actions performed on a set of primitive shapes rather than from observation. The algorithm simulates possible analogues of ontogenetic series based on principles similar to those that regulate plant and animal growth. She uses two sets of cards representing primitive shapes and actions, and randomly chooses a sequence of cards to decide what shapes to draw and what actions to perform. Using this algorithm, she developed a new body of work that she calls Isomorphogenesis.

The project liberated some mathematical shapes from the strict confines of their mathematical cradle, and it liberated Gemma from her naturalistic observational method[3]. On his part, Alessio is pleased to see that something has migrated from Morse theory into Gemma's art.

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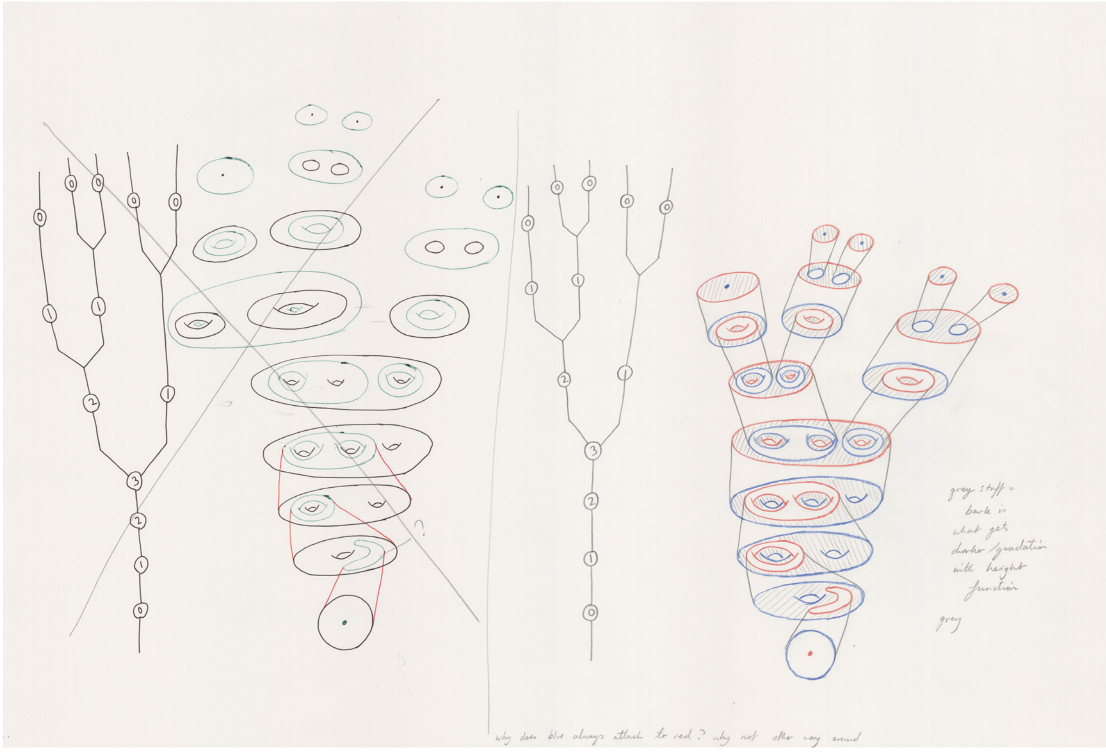
3 Important to note that while Gemma's style of observation was 'naturalistic' her artistic output has never been, nor tried to be.



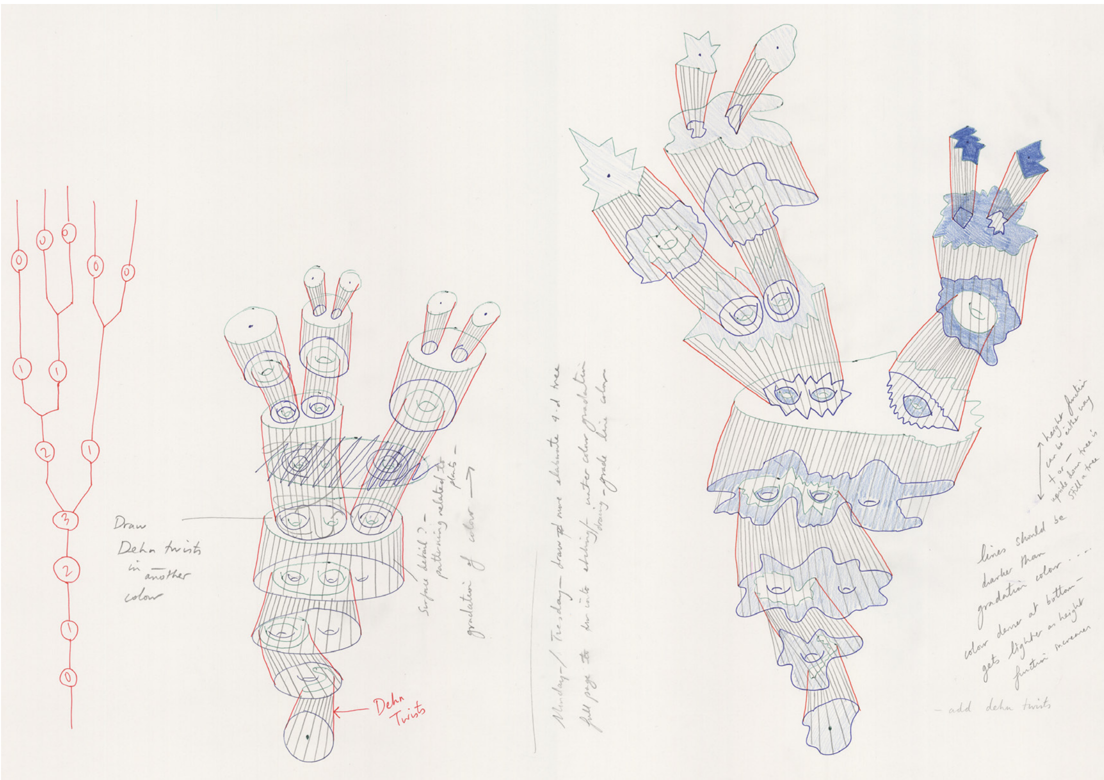


Figure 7. (top)
ANDERSON, Gemma, 2013. 4D Tree no.1,
Pen on paper,

Figure 8.
ANDERSON, Gemma, 2013. 4D Tree no.2,
Pen on paper.

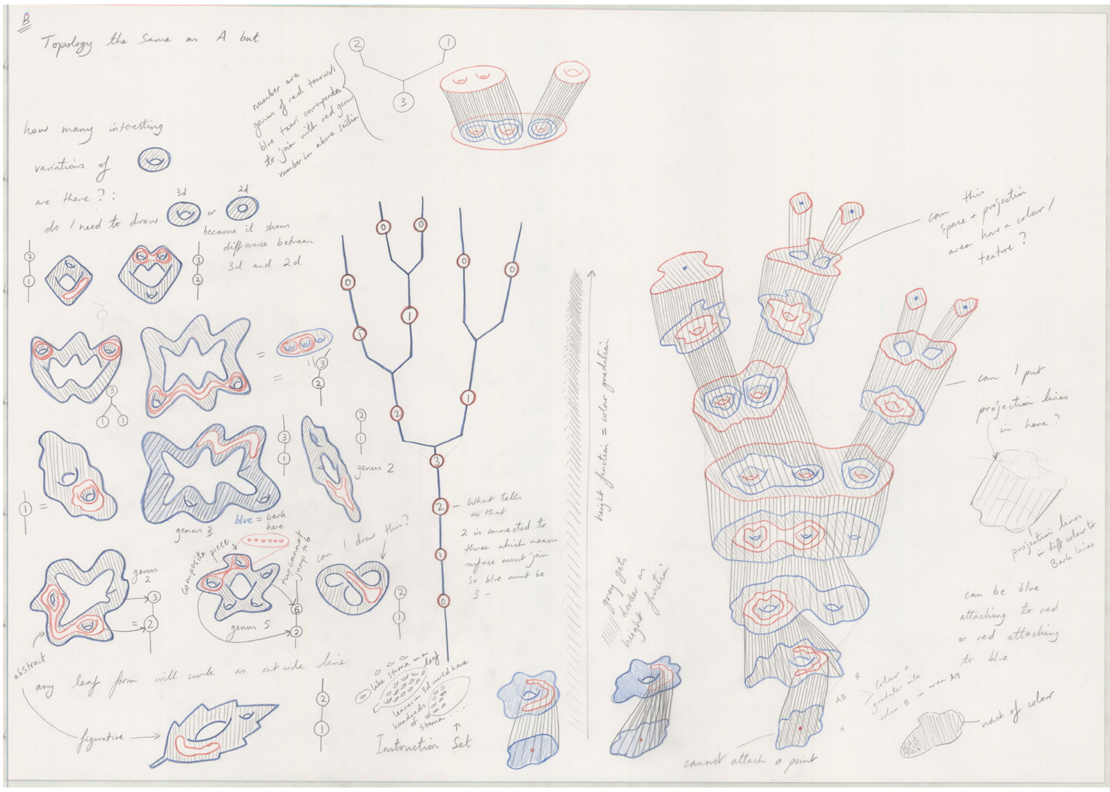


Figure 9.
ANDERSON, Gemma, 2013. 4D Tree no.3,
Pen on paper.

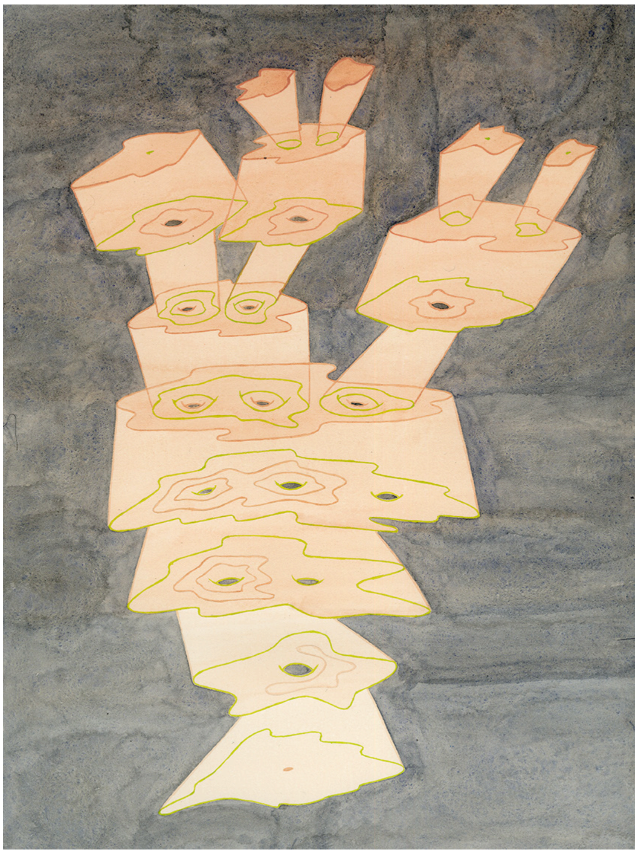


Figure 10.
ANDERSON, Gemma, 2013. 4D Morse Theory Tree

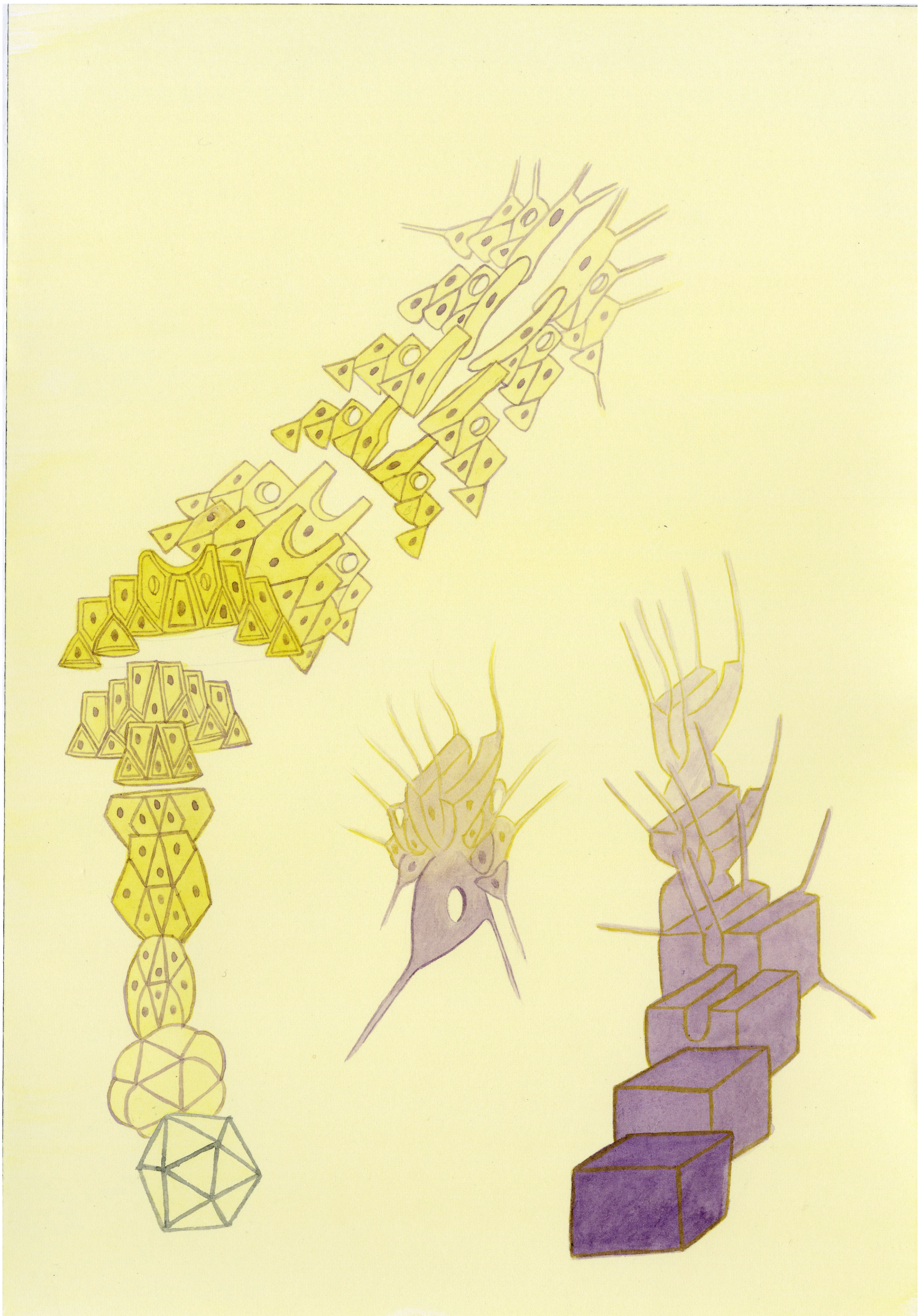


Figure 11.
ANDERSON, Gemma, 2014.
Isomorphogenesis no. 3. Watercolour on Paper.

Chapter Eight

Isomorphogenesis: Drawing a dynamic morphology

Chapter six explored the relationship between Klee and Goethe, touching on D'Arcy Thompson's influence on Klee and the ways in which Klee tried to represent the formative and dynamic nature of morphology. The previous chapter 'Notes from an Artistic Collaboration' explored the process of understanding, working in collaboration with mathematicians, how to draw a tree in the fourth spatial dimension. Together, these influences have inspired my own experimental approach to representing the dynamic nature of form.

This chapter introduces a further development in my artistic practice: 'Isomorphogenesis', a drawing practice or 'experiment' that explores the potentialities of representing morphology as a dynamic and formative process. Isomorphogenesis strongly builds on both the Isomorphology and Goethe inspired drawing methods as it progresses from the empirical study of the morphology of static museum specimens towards a conceptual study that aims to draw morphology as dynamic. This involves questioning the dynamics of formative process and has developed in communication with the European Research Council funded project 'A Process Philosophy for Biology', led by Professor John Dupré at the University of Exeter. This shift from an observational study of form has been a gradual development through the theory and practice outlined in previous chapters.

Isomorphogenesis brings together my experience of working with practitioners in theoretical and empirical branches of science (mainly at the Natural History Museum and Imperial College) in that it unites the observational and the abstract – experiment and theory – through drawing. This chapter represents the way I have applied theory from other domains – selecting key ideas based on my experience and knowledge – in parallel with the development of practice. Through the lens of Isomorphogenesis, this harvesting of information has enabled the adaptation of key ideas from other domains to feed my own practice. As such Isomorphogenesis samples aspects from the work of others and employs theory in the service of practice.

Historical and contemporary concepts from the fields of natural science, mathematics, philosophy and art that investigate and interpret morphological development have

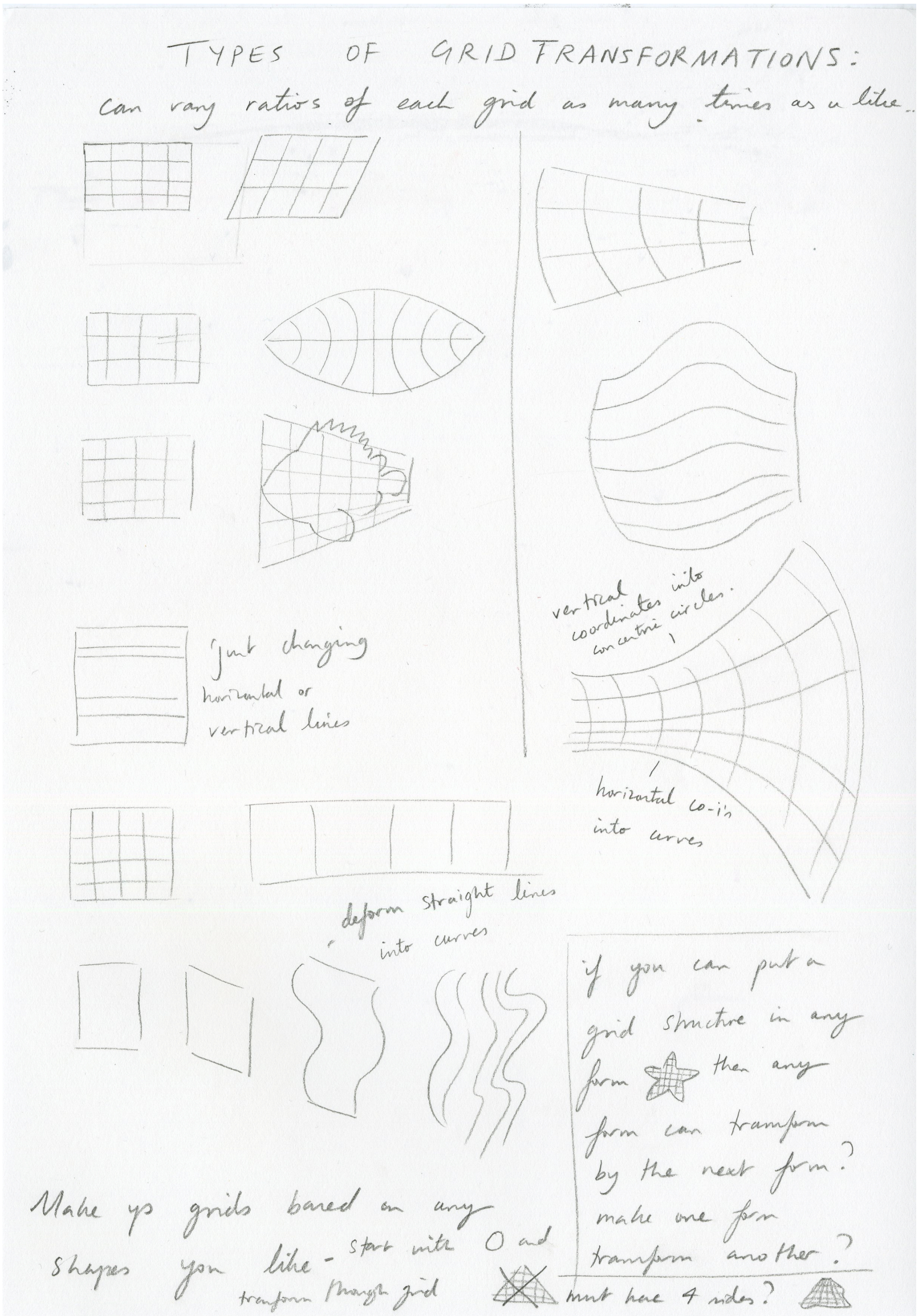


Figure 1.a.
ANDERSON, Gemma. 2014 Drawings of D'Arcy Thompson's Theory of Transformations, Pencil on Paper.

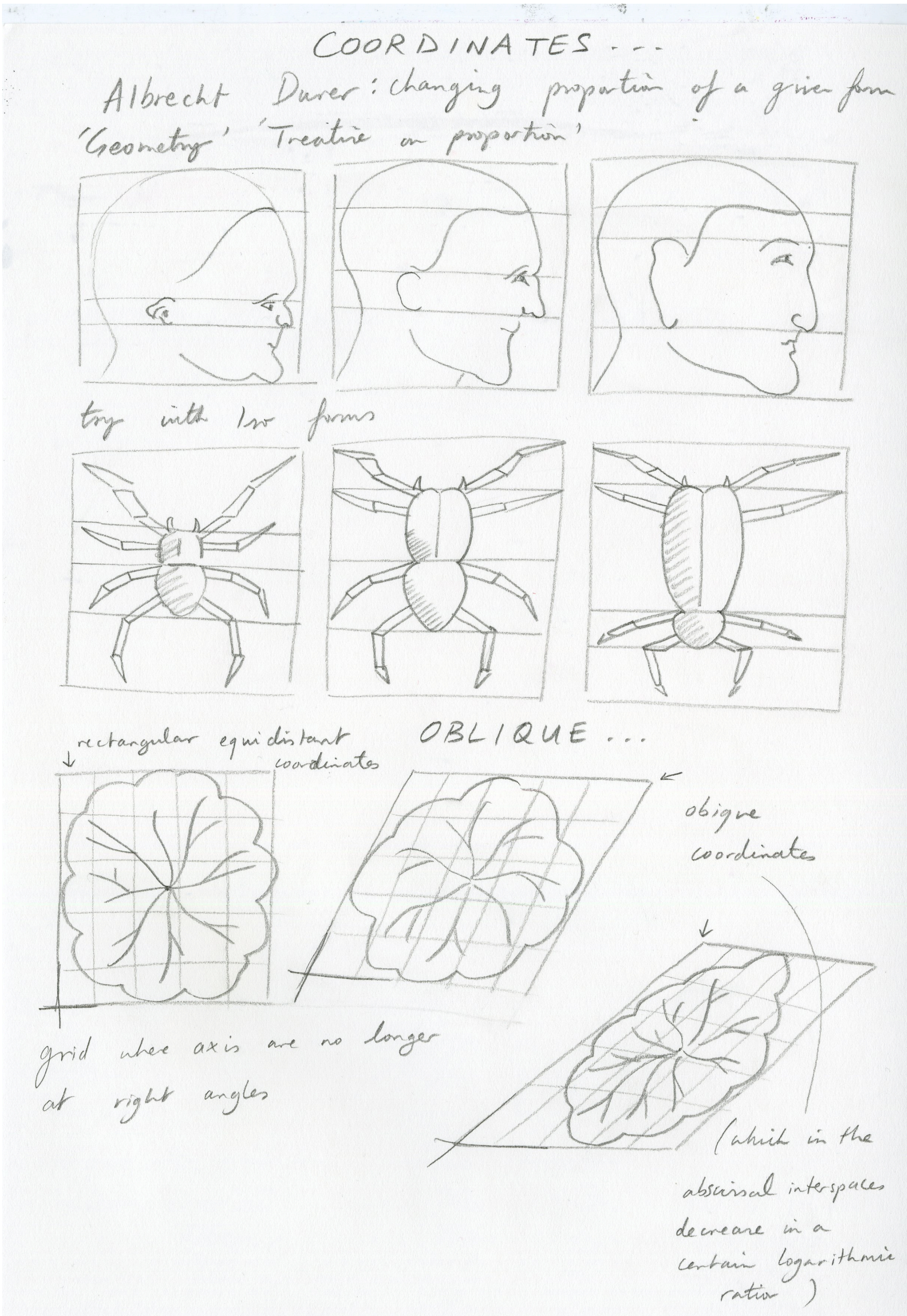


Figure 1.b.
ANDERSON, Gemma. 2014 Drawings of D'Arcy Thompson's Theory of Transformations, Pencil on Paper.

informed Isomorphogenesis. I begin this chapter with a discussion of D'Arcy Thompson's *On Growth and Form* (1917), which famously combined biological and mathematical concepts in a work of scientific prose and influenced artistic representations of dynamic form. I then introduce the biological concept of Theoretical Morphology (George McGhee), and the artistic 'FormSynth' system (William Latham). I go on to reveal how I have adapted Latham's FormSynth method to incorporate elements from my own observations and research, including the specific influence of D'Arcy Thompson on the development of Isomorphogenesis. Following this, I present an account of my own experiments with the Isomorphogenesis drawing method during a residency in Ireland in the summer of 2014, and then further experiments with the Isomorphogenesis method in the form of drawing workshops. Throughout, I relate to the conceptual frameworks of Theoretical Morphology (TM) , ontogeny and process biology as a way to interpret the artworks 'Isomorphogenesis 1-14', and to further bring experiment and theory together.

Artistic representations of development: The influence of D'Arcy Thompson's *On Growth and Form* (1917)

A particular influence on a number of artists who have engaged with morphology and the representation of the dynamic nature of form is the work of the early twentieth-century Scottish scientist and writer D'Arcy Wentworth Thompson. Thompson was Professor of Biology at University College Dundee for over thirty years until he became Professor of Natural History at the University of St Andrews in 1917, the same year he published *On Growth and Form* (Thompson, 1917). *On Growth and Form* encourages a rethinking of the familiar through careful observation and the application of mathematical understanding to a wide range of biological phenomena, including cell division, the effects of surface and gravitational forces, the shape of splash patterns, the logarithmic spiral in Foraminifera and the mechanical efficiency of skeletal structures.

As an artist, what I find so appealing about *On Growth and Form* is Thompson's ability to draw unconventional relations between biological forms, which challenge the conventions of the Linnaean scientific taxonomy of his time, and his ability to theorise on the dynamic nature of form. Art historian Martin Kemp sums up this characteristic of *On Growth and Form* as 'a work of biology that works across the boundaries of taxonomies' (Kemp in Jarron, 2014: 44). Kemp also notes Thompson's interpretation of the relationships of form independently from evolutionary lineage and coined the term 'structural intuitions' to describe the long tradition of artists' attraction to patterns in nature. He describes this term as 'a very deep sense of intuition about how things are behaving: statically and dynamically…' (Kemp in Jarron 2014: 38). I relate Kemp's term 'structural intuitions' as being connected to the intuitions that underlie Thompson's *On Growth and Form* as well as my own Isomorphology study.

Of particular interest to this study is Thompson's 'Theory of Transformations' and his Cartesian grid method which emphasises the importance of studying form change under all aspects and conditions (Jarron, 2014: 70). Thompson describes this theory thus:

> We might suppose that by the combined action of appropriate forces, any material form could be transformed into any other: just as out of a 'shapeless' mass of clay the potter or the sculptor models his artistic product; or just as we attribute to nature herself the power to effect the gradual and successive transformation of the simple germ into the complex organism (Thompson, 1942: 272).

I have explored elements of Thompson's Theory of Transformations through a series of drawings (Fig.1).

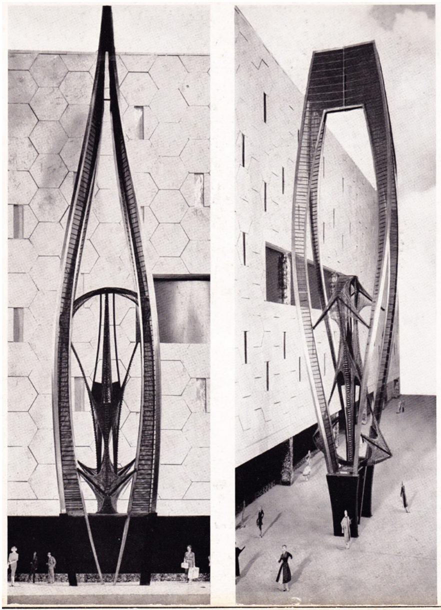
Thompson's influence on artists

On Growth and Form is described by Stephen Gould as: 'the greatest work of prose in twentieth century science' (Gould, 1992: ix). Thompson's love of analogy and metaphor is reflected in his poetic descriptions of the aesthetic qualities of organisms and mathematical patterns, prose which later became an inspiration to many artists.

This influence was recognised during the 1940's by art historian Herbert Read who introduced the book to the artists commonly associated with St Ives, including Barbara Hepworth, Naum Gabo and László Moholy-Nagy[1]. Naum Gabo's observations of the structure of trees paralleled his reading of *On Growth and Form* and the work 'Bijenkorf Construction' Rotterdam (Fig.2)(1954-1957) reflects this confluence. The twisting planes of Gabo's earlier work 'Crystal' (Fig.3)(1937) are suggestive of this affinity to Thompson's work, as is 'Spheric theme' (Fig.4)(1937) which follows structural laws of aggregate cells with incised curving planes in spherical space. Henry Moore's[2] (a contemporary of Gabo) familiarity with *On Growth and Form* is tangible in the way the 'Transformation Drawings' (Fig.5) evidence his experience of form change as temporal, as one shape mutates into another.

1 Moholy-Nagy later referred to Thompson in his Vision in Motion Book, Moholy-Nagy, L. 1969. While Moholy-Nagy may have visited Cornwall, he never lived there (he went from the Bauhaus to the Netherlands to London to Chicago).

2 Moore was inspired by *On Growth and Form* as a student at Leeds College of Art in 1919 (Jarron 2014)



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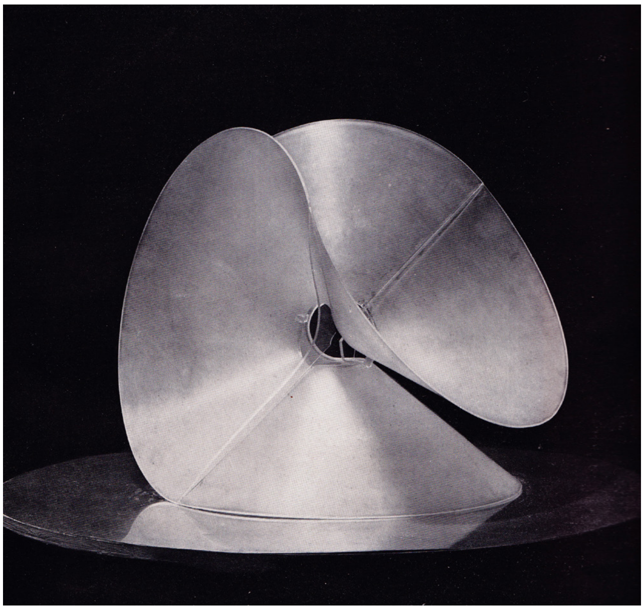

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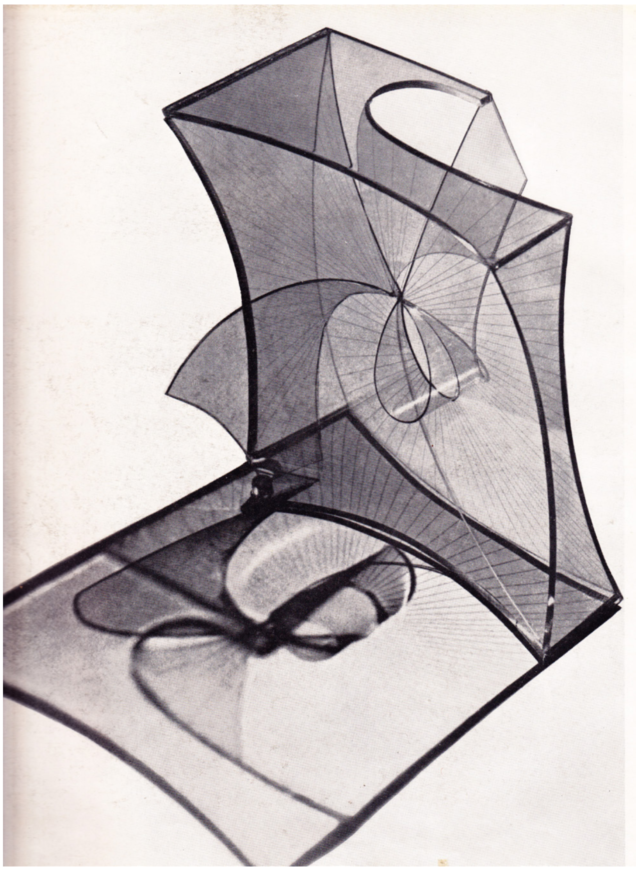

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Figure 2.
GABO, Naum, 1958 Bijenkorf Construction, Sculpture. From Read, H. (1957) Gabo. Edited by Leslie Martin. London: Lund Humphries.p.99
Figure 3.
GABO, Naum, 1937-9 Crystal, Cellulose Acetate, 220x270x180
Available at: http://www.tate.org.uk/art/artworks/gabo-construction-in-space-crystal-t06978/text-display-caption. From Read, H. (1957) Gabo. Edited by Leslie Martin. London: Lund Humphries.
Figure 4.
GABO, Naum, 1937 Spheric Theme, Plastic, 83x102x83 mm. From Read, H. (1957) Gabo. Edited by Leslie Martin. London: Lund Humphries.. Available at: http://www.tate.org.uk/art/artworks/gabo-model-for-spheric-theme-t02173

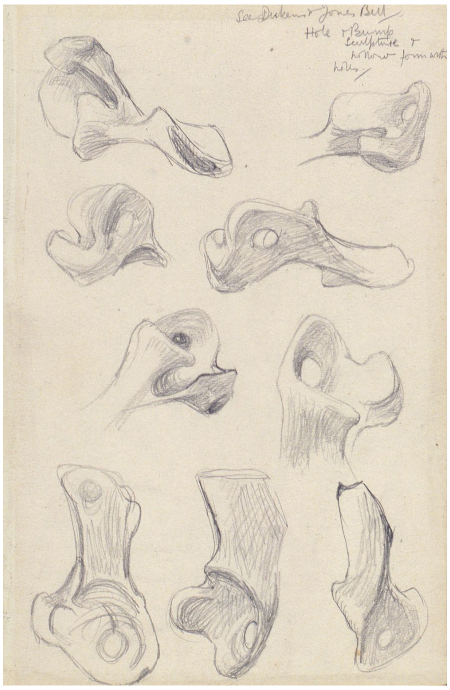


Figure 5.
MOORE, Henry, 1932 Ideas for Sculpture: Transformation of Bones , pencil on paper ©The Henry Moore Foundation. All rights reserved; Photo: The Henry Moore Foundation archive. Available at: http://www.tate.org.uk/art/research-publications/henry-moore/edward-juler-life-forms-henry-moore-morphology-and-biologism-in-the-interwar-years-r1151314

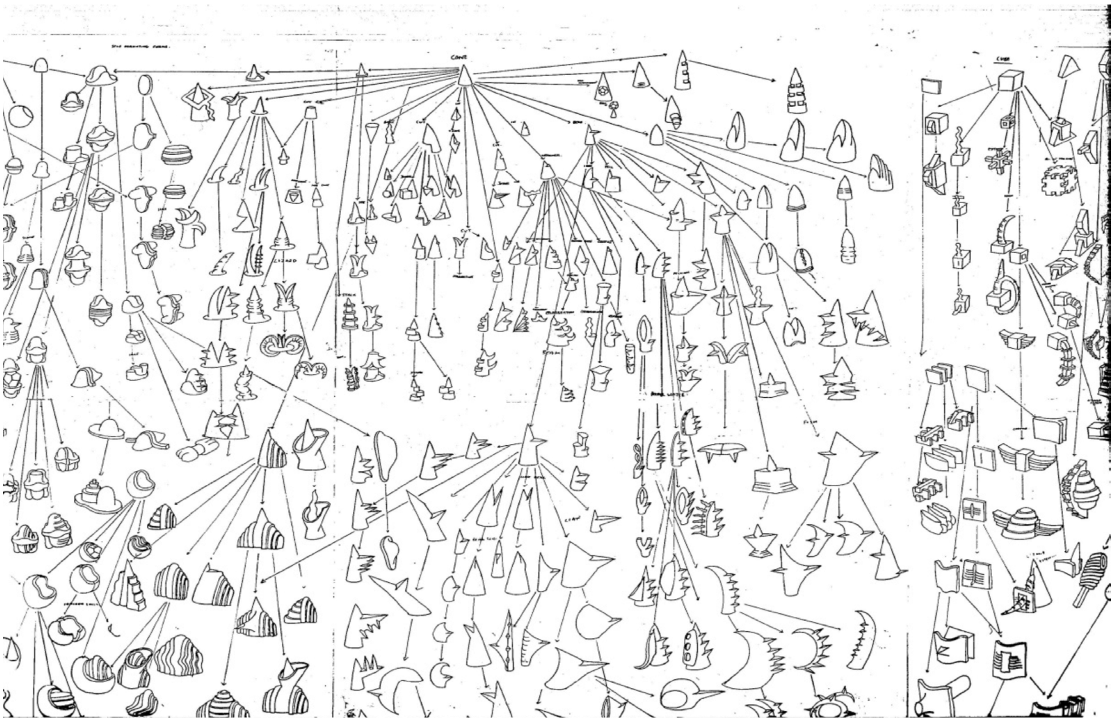
In London in the 1940s, the young Richard Hamilton discovered *On Growth and Form* while at the Slade School of Art and related its energising influence, saying '*On Growth and Form* charged my batteries for a number of years' (Hamilton, 1982: 11). While reading the book, Hamilton was inspired to expand artists' visual vocabulary through increased exposure to scientific imagery and ideas. He later appropriated *On Growth and Form* as the title for his landmark exhibition at London's Institute of Contemporary Art in 1951[3]. This influence has been celebrated in the recent exhibitions[4] 'Richard Hamilton' (Tate 2014) and 'D'Arcy Thompson's *On Growth and Form'* at the Henry Moore Institute, Leeds (2014)[5].

Building on this select history of artists, who have been influenced by *On Growth and Form*, I will later reveal how I have integrated elements of Thompson's grid transformation approach into the drawing method 'Isomorphogenesis'.

Thompson's influence on computer generated art and William Latham

On Growth and Form has been foundational to early pioneers of computer art, such as Roy Ascott and Desmond Paul Henry. More recently, contemporary artists William Latham, Bruce Gernard and Andy Lomas[6] have used computer technology in a creative way to make 'generative art' which also draws upon Thompson's work.

3 Which coincided with the Festival of Britain.
4 A room from the original exhibition '*On Growth and Form*' at the ICA was reconstructed for Tate Modern's Hamilton exhibition in 2014, which I visited. Among the reconstructions were display cabinets with various objects including a horse's skull, goat vertebrae, and eggs; illuminated glass negatives, photomicrography, electron-micrographs, radiographs and photograms; films of crystal formation and cell growth of a sea urchin.
5 Matthew Jarron, curator of D'Arcy Thompson Museum's collections continues to explore the relationship between Thompson's work and art in exhibitions like 'living structures' 2013.
6 Andy Lomas, who has created digital effects for Avatar and The Matrix films while also exhibiting his algorithm-derived art prints in galleries, citing Thompson as his key influence. See appendix for more details about Lomas' work (Other examples include McCabe and Simms).



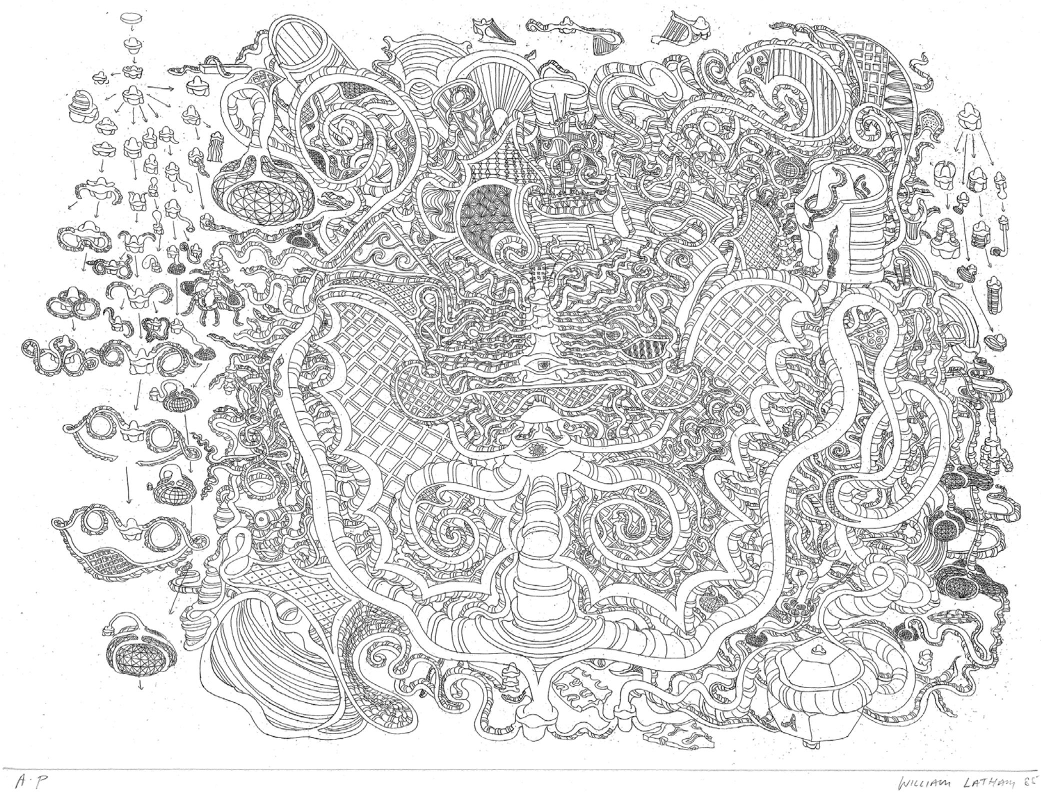


Figure 6.
LATHAM, William, 1985 FormSynth, Pen on paper, 84x118cm. Copyright William Latham
Figure 7.
LATHAM, William, 1986 Empire of Form, Pen on paper, 84x118cm. Copyright William Latham

Of these artists, Latham is of particular importance to this research. In 2011, I met with Latham[7] at Goldsmiths (where he is Professor of Creative Computing) to discuss the relationship between the set of primitive forms selected for the Isomorphology study and those of his Mutator computer programme. Latham developed Mutator during his time at IBM (1987-93) as a step-by-step accretion of 'operations', with actions which are applied to primitive forms (including cones, spheres and torus forms amongst others) through a computer algorithm. During our conversation, I asked Latham about the influence of Thompson on his work, he responded as follows:

> I remember seeing D'Arcy Thompson's work in the book '*On Growth and Form*' for the first time (in the 1980's), and being immediately struck by his basic idea of schematising nature from another high level perspective and the idea of rebuilding biological forms based on mathematical principles and the recurrent use of spirals (Latham, personal communication, 2014).

This influence can be found in the recurring spiral themes and biological forms, which Latham evolves through his Mutator creative computing program. Later in 2013, during a visit to Latham's exhibition 'Mutator 1+2: Evolutionary Art by William Latham', (Latham, 2014) I had the opportunity to study the analogue drawings 'FormSynth' (1985)(Fig.6) and The 'Empire of Form' (1986[8])(Fig.7), produced through a drawing system that preceded 'Mutator,' which Latham calls 'FormSynth' (1985)(Fig.6).

Of these drawings, The 'Empire of Form' (1986) evolves form through drawing 'rules' (see Fig.11), reminding me of Richard Serra's 'Verb List'(1967-68[9]) (Fig.8) and reveals the systematic process behind the Mutator computer programme as a simple hand drawn flow-system which Latham called 'FormSynth'. In the drawings 'The Empire of Form' (1986) and 'Black Crystal' (1986) Latham draws what he defines as 'Euclidean primitives' at the top of a page and then draws the evolution of these forms through a set of 'rules' by following the 'FormSynth' flow-system. Latham reflects on how 'FormSynth' developed in his book *The Conquest of Form*:

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7 William Latham is a contemporary artist who uses algorithms to simulate the development of form. He began his career at the Royal College of Art (1983-1985). Notable influences on Latham's work include the surrealists, systems art and evolutionary developmental science. During his time as Artist in Residence with IBM (International Business Machines) between 1987 and 1993, Latham was one of the first UK computer artists to blend organic imagery and computer animation software.

8 Developed while he was at the RCA

9 Serra includes many of the same verbs as found in Latham's 'rules', e.g: twist, rotate and split.

I produced a large drawing called 'the evolution of form' which came into being before I had started to use computer graphics and shows the principles behind all my work. At the top of the drawing a number of geometric primitives (cone, cube, sphere, cylinder and torus) which gradually evolve into more complex forms as they near the bottom of the drawing. I devised a set of rules which defined sculptural transformations. These were 'beak', 'bulge', 'scoop', 'union', 'twist' and 'stretch'. By carrying out these transformations repeatedly and in different sequences on a geometric form, different types of complex form could be evolved (Latham, 1990: 8).

Figure 8.
SERRA, Richard, 1967–68 Verb List. Graphite on paper, 2 sheets, each 10 x 8" (25.4 x 20.3 cm). The Museum of Modern Art, New York. Gift of the artist in honor of Wynn Kramarsky. © 2011 Richard Serra/Artists Rights Society (ARS), New York. Available at: http://www.moma.org/explore/inside_out/2011/10/20/to-collect

I interpret Latham's drawings as an abstract developmental series, similar to those of Klee (see page 215) but more systematic in approach, resulting in tree-like arrangements of form or 'phylogenies' of form, whereas Klee's 'Suspended Plants' (1921) present a more linear evolution. Another feature which distinguishes Klee and Latham is that the *FormSynth* flow system gives the option to 'marry' form, which Latham defines as the ability to 'maintain characteristics of both parents', to produce a 'progeny' or descendent form. When Latham first developed *FormSynth* in 1985 he had not yet developed a way for the computer to 'marry' forms. Interestingly, when this later became possible[10] Latham reflected that 'drawing is still generally better at 'marrying' form than a computer which, rather than maintain characteristics of both parents, creates an average form' (Latham, email exchange, 2014). Latham's statement provides practice-based evidence of the currency of drawing when applied to the marrying of form.

During a drawing workshop[11], to which I was invited by Latham, I learned how primitive forms are evolved through the 'FormSynth' drawing rules. This experience inspired me to adapt the FormSynth flow system (which is a simple algorithm) by adding a new set of parameters to create my own artistic representation of the dynamic nature of form. In this context, the term parameter is intended as a characteristic or feature (in this case mainly verbs) that can help define a particular system, and an algorithm is a specific set or sequence of unambiguous instructions for carrying out the procedure of drawing.

While artistic experiments with algorithms are largely associated with computing[12], parameters have been recognised as important for the creative practice of artists who work with or without computers since the process art movement of the 1960s. This is visible through the work of Richard Serra's 'Verb List', Brian Eno's Oblique Strategies[13], and Sol le Witt's Wall drawings[14], amongst others[15]. What connects all of these works is some level of interaction between the artist and a system with rules. This can be either physical mark making, or a mental shaping of the parameters by creating the rule set

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10 At IBM, Latham developed forms through a numerical code which defined the sculptural transformations such as the amount of stretch or twist or the number of primitives being 'married'. Latham describes how the newly evolved form is first displayed as a line drawing on the computer after which he chooses a viewpoint, then passes its data to WINSOM solid modeller where it is 'textured, lit, given surface qualities, ray-traced and coloured to give a realistic representation of the sculpture; the larger the sequence of numbers input to the computer evolution programme the greater the complexity of form will be evolved. The code can itself be modified through changing the parameters. and by adding more parameters the form can 'evolve' into a more complex state.

11 At the Phoenix Gallery during his exhibition 'Mutator 1+2: Evolutionary Art by William Latham' in September 2013

12 Algorithmic art, also known as computer-generated art, is a subset of generative art and is related to systems art. Fractal art is an example of algorithmic art.

13 Oblique Strategies (subtitled Over One Hundred Worthwhile Dilemmas) is a deck of 7-by-9-centimetre (2.8 in × 3.5 in) printed cards in a black container box, created by Brian Eno and Peter Schmidt and first published in 1975. Each card offers an aphorism intended to help artists (particularly musicians) break creative blocks by encouraging lateral thinking.

14 Sol le Witt's 'Scribble wall drawings' involved a system where different areas where broken down into sections and labelled 0-6: zero being white (devoid of pencil marks) and six being dense scribbles. These instructions were then interpreted in different ways, allowing interesting and unforeseen things to happen.

15 For example: James Sienna's, Clint Fulkerson. The use of algorithm and coding in art has led to the emergence of the genre of 'DevArt' (Schmidt) as recently explored in the 'Digital Revolution' (2014)exhibition at the Barbican in the work of Karsten Smidt, Zach Lieberman and William Latham's 'Mutator'. A characteristic of 'DevArt' is the role of parameters as fundamental to create computer generated artforms.

or adapting the system and through visualisation before drawing; or a hybrid of both to achieve otherwise impossible or unpredictable results. The intention of this kind of work can also be understood as an exploration of what might happen if control is partially transferred from the artist to a system.

An interesting contemporary example of experimentation with parameters, also influenced by Thompson, can be seen in the work of the sculptor Bruce Gernard. In the project *Coded Chimera* (2010) Gernard collaborated with morphologist Norman MacLeod at the Natural History Museum and scientists at the Cambridge Computer Lab to explore the relationship between sculptural form-making and biological morphogenesis through computer modelling. Taking Thompson's transformation diagrams as a starting point, Gernard used scans of animal specimens and a 'MorphTool' in the Cambridge Computer Lab, which included instructions such as 'warping', in combination with a 'marching cubes' specialized algorithm to morph and blend digital meshes of different species to convey qualities of fluidity and mutability. This links the use of modern technology back to ancient ideas of the chimera. Gernard's process also links in particular to Thompson's Transformation Grids and the idea of an organism being a 'diagram of forces that have acted upon it' (Jarron, 2014: 39).

Like Latham and Gernard, I am interested in using parameters and flow systems (or algorithms) to simulate morphogenesis (or biological development), but where Latham experiments with parameters and algorithms to test the generative possibilities of the computer, and Gernard those of the computer generated sculpture, my intention is to test the generative possibilities of drawing. The artistic exploration of generating possible or 'theoretical' evolutions of form (morphogenesis) by working with a set of parameters and an algorithm has methodological and conceptual parallels with the contemporary scientific field of 'theoretical morphology' which I will now discuss.

Theoretical morphology

Norman Macleod introduced me to the concept of 'Theoretical Morphology' (TM) during discussions about Isomorphology at the NHM (2012-2013) through the aid of this metaphor:

> The actual animals that have ever lived on earth are a tiny subset of the theoretical animals that could exist. These real animals are the products of a very small number of evolutionary trajectories through genetic space …. each perched in its own unique place in genetic hyperspace. Each real animal is surrounded by a

> little cluster of neighbours, most of whom have never existed, but a few of whom are its ancestors, its descendants and its cousins. Sitting somewhere in this huge mathematical space are humans and hyenas, amoebas and aardvarks, flatworms and squids, dodos and dinosaurs'. (Dawkins, 1987: 73)

This notion that extant organismal forms are only a subset of the range of theoretically possible morphologies that underlie the field of TM[16] can be traced back to the writings of Cuvier, Carus, Bronn and Haeckel (Russell, 1968), and continues in the contemporary field of TM (Raup and Michelson 1965, McGhee 1980). TM is defined in scientific terms as 'the tool by which we can document the range of actual structures that have evolved in the history of life as a subset of the structures that are theoretically possible' (Hickman 1993:170). In the book *Theoretical Morphology*, George McGhee outlines the priority of TM when he says, 'it is important to look at what is theoretically possible as it gives us insight into possible morphologies; the more we understand life forms the more we understand life processes' (McGhee, 1999: 112[17]). In TM McGhee outlines the common misconception that exercises of TM (and its morphospaces) must be the product of complex mathematics and sophisticated computer programmes. He emphasizes that TM is not concerned with the precise mathematical description of any given existing form, but instead asserts that 'the creation and examination of non-existent form is often of more interest in theoretical morphology than the examination of existent form' (McGhee, 1999: 4).

I am interested in how a drawing method that explores theoretical possibilities of form based on principles of development can be considered as an exercise in Theoretical Morphology. I proposed this idea to McGhee, who responded by saying that a drawing (especially one which works with a set of parameters) can be considered as an exercise of theoretical morphology, relating to an example of his own drawing:

> Art can be used to depict both existent and create nonexistent form. Artists have been doing so for centuries (long before theoretical morphology was born), and Science Fiction artists continue to do so now with the medium of movies (I really liked the six-limbed-vertebrate creatures in Avatar). I think the only difference

16 The term Theoretical Morphology was first used by E.S Russell in Form and Function: A contribution to the history of Animal Morphology (Russell 1916, 1982:33)

17 The environment and conditions, etc determine fitness to survive of all the possible configurations – Darwinian natural selection. Isomorphogenesis is aware that there is always a context or ecosystem and will work towards a consideration of environmental factors in future research.

> in Theoretical Morphology is the spatial context, instead of isolated sketches of non-existent forms (Cyclops, Dragons, Centaurs, etc.) the non-existent forms of theoretical morphology occur in a smooth continuum of transitional forms that range from existent to non-existent in a morphospace. Yet I see no methodological reason that an artist cannot do the same (McGhee, email exchange, June 2014).

This reveals that although TM is often of a computational nature it is not defined by computation and affirms that drawing can also explore what are the theoretical possibilities of form in order to enhance the understanding of existing forms. The drawing space can offer a freedom to explore possibilities of existent form, providing a theoretical (or conceptual) study of form, which resonates with Thompson's co-ordinate method and his reflection on the exploration of possible forms:

> 'We have dealt so far, and for the most part we shall continue to deal, with our co-ordinate method as a means of comparing one known structure with another. But it is obvious, as I have said, that it may also be employed for drawing hypothetical structures, on the assumption that they have varied from a known form in some definite way. And this process may be especially useful, and will be most obviously legitimate, when we apply it to the particular case of representing intermediate stages between two forms which are actually known to exist, in other words, of reconstructing the traditional stages through which the course of evolution must have successively travelled if it has brought about the change from some ancestral type to its presumed descendant' (Thompson, 1942: 300)[18].

Dupré's process philosophy of Biology

There is a tradition in biology to think of biological entities as things or 'objects' rather than processes. John Dupré's philosophy of biology proposes the application of a process-oriented ontology to biological entities. This ontological shift provides a new context and opportunity to think about how to represent and understand biological entities as dynamic processes, which this study begins to address.

Dupré addresses the ancient and fundamental ontological issue of biology: 'whether the living world should be thought of as a hierarchy of objects, or rather as composed of

18 'Coded Chimera' (2010) was a collaboration between artist Bruce Gernand (UAL) and Morphologist Norman MacLeod (NHM) which joined models of biological growth with computer technologies to explore new ways of sculptural form making through the construction of animal hybrids with emphasis on intermediary stages and those which defy the conventions of taxonomy.

processes, and thus as essentially dynamic' (Bapteste and Dupré, 2013: 379). Dupré has collaborated with the evolutionary biologist Eric Bapteste[19] to study the dynamics within biological (especially microbial) systems and together they conclude that a view of the biological as 'object' is limiting. Bapteste and Dupré propose a 'sketch' of a 'network-based ontology' which Bapteste and Dupré argue is necessary to represent a diverse set of processes. This 'sketch' is not a drawing – it is an argument which is supported by diagrammatic images.

Building on the work of Eigen[20], Bapteste and Dupré describe a need for a typology of processes, and call for a study of intersecting processes that create 'systems', 'assemblages composed of heterogeneous parts in functional interaction with recurrent phenotypes' (Bapteste and Dupré 2013: 380). Just as the Isomorphology study developed a typology of form, Dupré and I have recognised the potential for the Isomorphogenesis method (see page 272) to create a typology of process, along with methods for representing this. This would involve identifying heterogeneous biological processes through similar methods used to identify heterogeneous forms in the Isomorphology study. Isomorphogenesis reveals a series of drawing actions that explore the nature of primitive and developed form, as assemblages created through the Isomorphogenesis (systematic) drawing process. The first Isomorphogenesis series evolves form in a more or less 'vertical descent' way but future iterations could be developed to evolve form through network-based models. Isomorphogenesis offers drawing 'actions' (movements or principles) which re-enact movements of biological processes, and begins to classify these 'actions' into primary and secondary categories by organising them in two categories during the drawing process (see page 273).

In the chapter 'Processes of Life' (Dupré, 2012) Dupré describes how mechanistic models are inadequate to provide a full picture of life as a dynamic system, and says 'key concepts in biology are static abstractions from life processes'. This is a fundamental reason why these concepts defy unitary definitions. Dupré also states that nature does not determine for us any unique mode of abstraction; and therefore approaches to abstracting from and representing nature can be pluralistic, a view which permits Isomorphogenesis to join the myriad of possible ways to offer insight into the dynamic nature of biological form.

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19 Bapteste is an evolutionary Biologist at the Universite Pierre and Marie Curie, Paris, France.

20 Eigen (b.1927) won the Nobel Prize in Chemistry in 1967. Publications include "Steps towards life: a perspective on evolution." (1992).

Isomorphogenesis suggests a classification of processual movements or 'actions' which has emerged through a drawing process rather than a traditionally scientific process and therefore relates to Bapteste's call for a typology of process. While a typology of process is useful to evolutionary biologists like Bapteste as a way to navigate and compare the interactions between life's spectacle, it is also useful to my artistic research as a way to inform drawing methods. Drawing becomes a way to gain insight into types of biological process through experimenting with artistic simulations and analogues[21].

Although Isomorphogenesis displays some analogous qualities with biological concepts of development, there is still much to be explored in this first series. I have evolved forms in a linear way while plant root systems evidence that it is also possible to evolve form in a non-linear way. It is also possible to experiment with evolving form in a phylogenetic[22] tree with first, second and third generation, as a reticulum[23] model of evolution. In Isomorphogenesis forms are evolved and can marry and hybridize at any point in the developmental series.

As a drawing process, Isomorphogenesis does not claim to directly contribute to the science of evolutionary biology; however, it does offer a method for representing, exploring and theorizing the processual nature of biology/morphology, which offers insight into biological development through drawing and has the potential to inform the ontological shift towards conceiving or theorizing of form as process. Future iterations will be developed in collaboration with Bapteste and Dupré to offer genuine insight into 'biology as process' through drawing methods that can be shared as an interdisciplinary epistemological tool.

I will now describe how I developed 'Isomorphogenesis' as my own exercise in theoretical morphology and an attempt at representing the dynamic/process nature of biological entities through drawing, which builds on Latham's Formsynth and Thompson's grid transformations and integrates elements from preceding chapters.

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21 There is then also the potential to apply a 'typology of process' to the artwork, as a form of interpretation in which biological research could shed light on artistic practice and even suggest a typology of artistic process.
22 In biology, phylogenetics is the study of evolutionary relationships among groups of organisms (e.g. species, populations), which are discovered through molecular sequencing data and morphological data matrices.
23 A fine or net-like structure.

Developing the Isomorphogenesis method

Isomorphogenesis aims to explore and to simulate through drawing the possibilities of form as an exercise in Theoretical Morphology that integrates Thompson's method of grid transformations, Klee's colour gradation (see page 191) and William Latham's 'FormSynth' system, as well as building on previous empirical and conceptual study of form outlined in this research project. Isomorphogenesis builds directly not only from Isomorphology but from my collaboration with mathematician Alessio Corti, especially on the methodology of drawing a tree in the fourth spatial dimension through adapting the mathematical 'Morse Theory' into a drawing method. In chapter seven 'Notes from an artistic collaboration' we interpreted the four-dimensional tree as an abstract ontogenetic series as we consider the concept of ontogeny useful to interpret both biological and abstract (mathematical) form.

The practice has developed through a series of initial experiments which relate to Bruce Gernand's observations of the nature of his own practice based research: 'Although one can make plans and project ideas in advance, there are also aleatoric structures, random occurrences: mutations begin to drive actions which are a lot less deterministic than we think' (Gernand, 2010: 5). Isomorphogenesis has developed from the struggle to find a method that would accommodate, and indeed capitalise on, the very uncertainty that characterises the creative process. In this case, uncertainty, often perceived as a limitation, provides the strength and impetus of the practice.

Initial experiments June 2014: adapting Latham's 'FormSynth' system and integrating elements from Isomorphology and Goethe's approach

During the summer of 2014 I spent two weeks as artist in residence at Cill Riallaig Artists Village (co.Kerry, Ireland)(Fig. 26.a and b) This section begins with a summary from my journal of practice (details of experimentation can be found in Appendix C.1) followed by reflections on this practice.

I began by drawing Latham's FormSynth flowchart (Fig.9) and adapting by adding drawing rules (or 'actions inspired by Thompson (see Appendix C.1.1), Klee and my own Isomorphology study (Fig.10 and 11). This has been complemented by the direct observation of plant growth and development across seasons, in the field, the study of principles of plant growth, the study of images and verbs associated with cell development in Developmental Biology (Gilbert, 1991) and plant growth, as defined in *The Cambridge Illustrated Glossary of Botanical Terms* (Hickey and King, 2000)(see Appendix C.1.2).

The influence of D'Arcy Thompson's grid transformations led to a number of drawing 'actions' which are best understood through the series of drawings presented earlier (see Fig.1): Vary horizontal lines, Vary vertical lines, Transform obliquely, Vary shape of grid. I also added a series of 'actions' to the flow system based on Thompson's work, specifically in relation to cylinders (Thompson, 1942: 53-60): Expand, Narrow, Thicken walls, Thin walls, Lateral shoot, Vertical shoot, Bend, Coil, Infold walls, Crimp walls, Bifurcate, Trifurcate, Transparency.

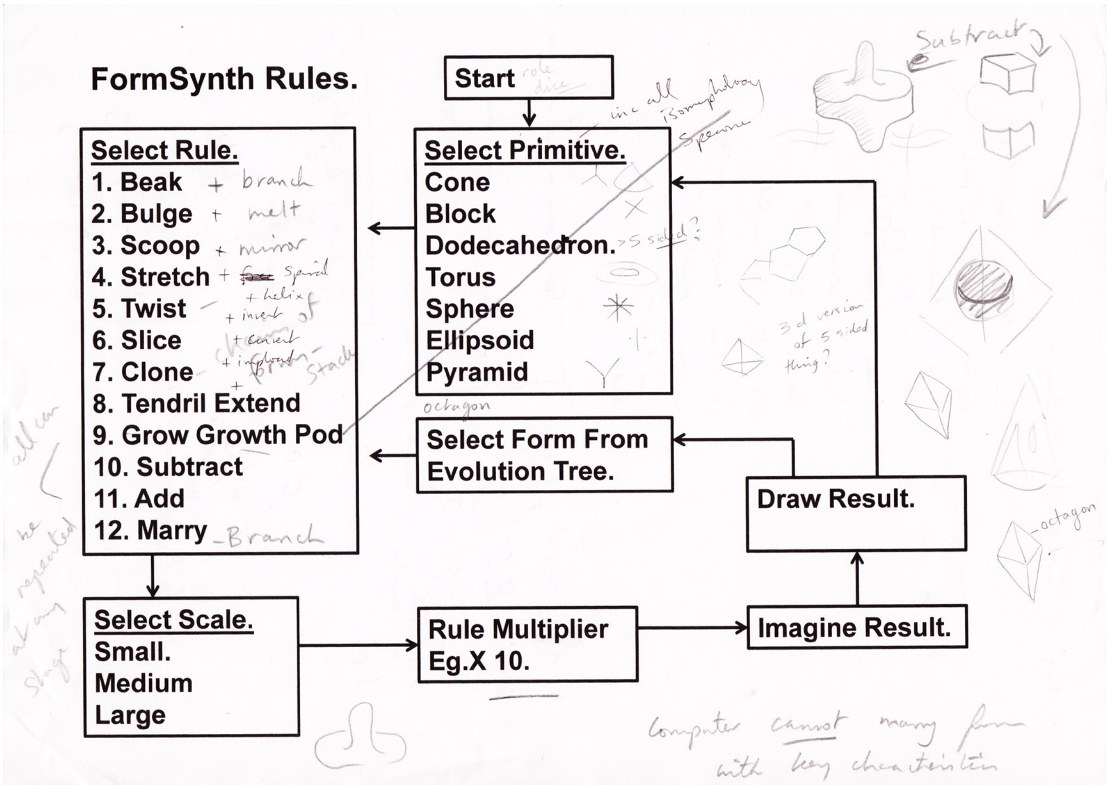


Figure 9.
LATHAM, William, 1986 Formsynth Flowchart, (with notation by ANDERSON, Gemma), 2014 (A4)

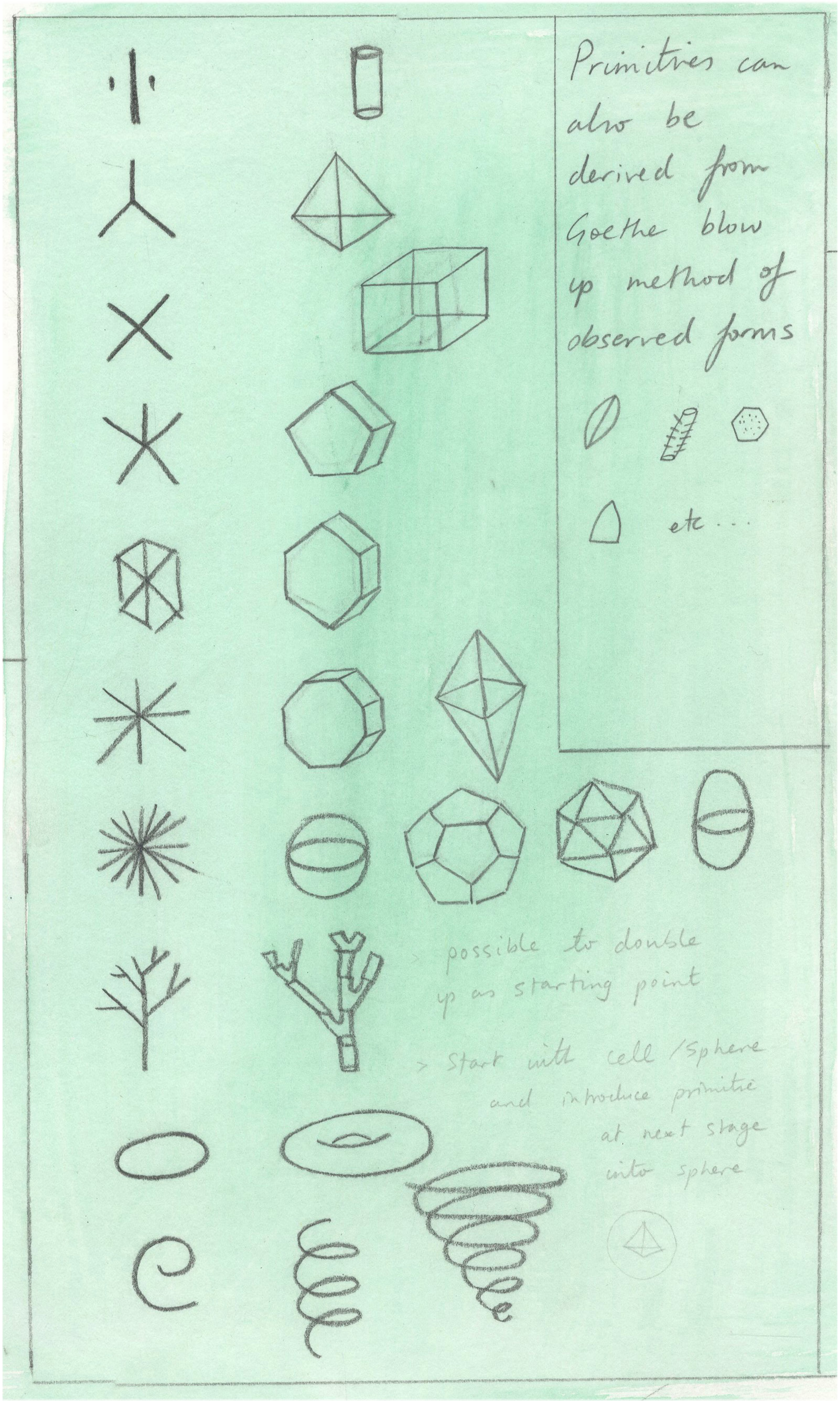
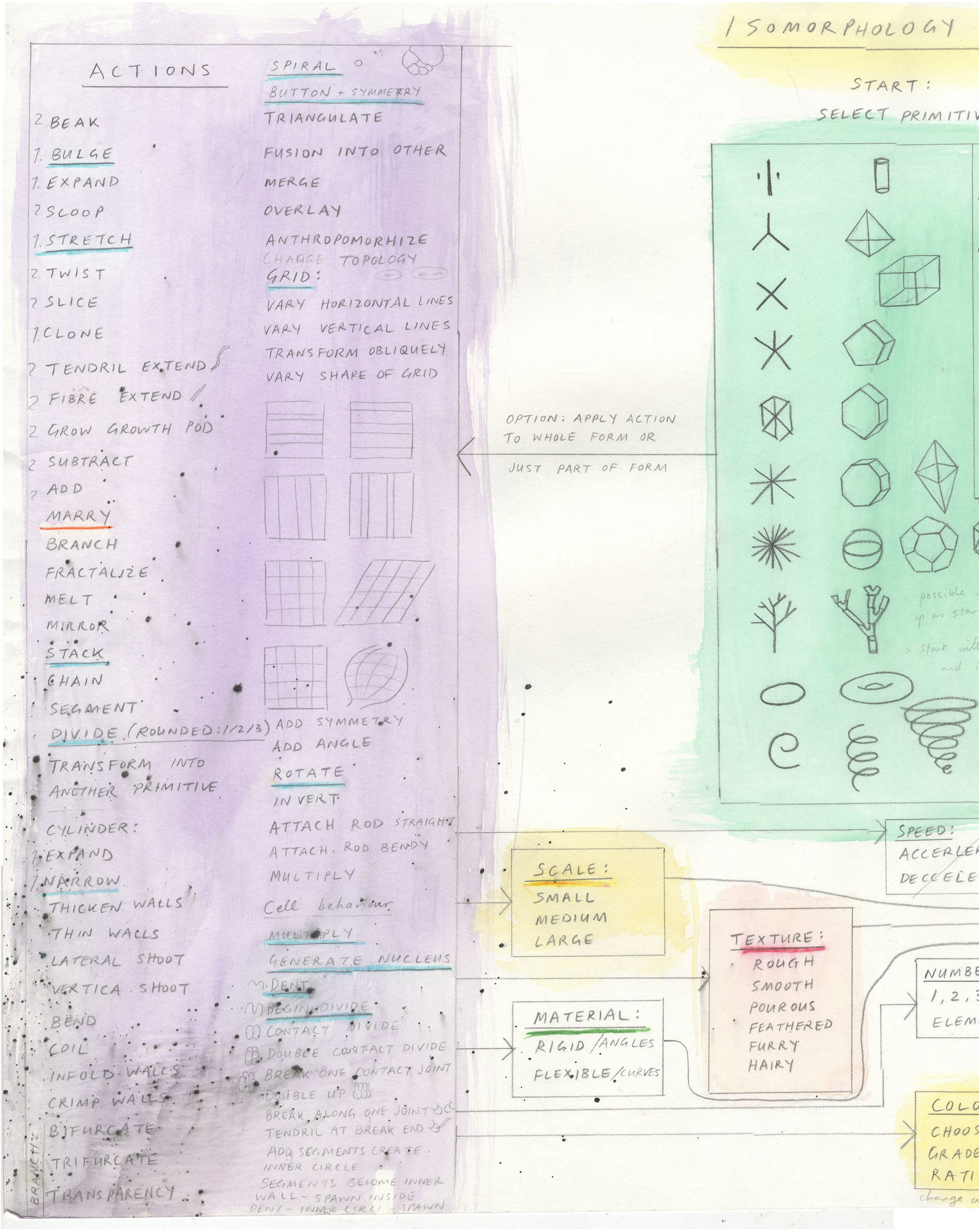


Figure 10.
ANDERSON, Gemma, 2014 Adapted formsynth flow system, (detail), pencil and watercolour on paper, (A2)


ACTIONS
2 BEAK
1. BULGE
1. EXPAND
2 SCOOP
1. STRETCH
2 TWIST
? SLICE
1. CLONE
? TENDRIL EXTEND
2 FIBRE EXTEND
2 GROW GROWTH POD
2 SUBTRACT
? ADD
MARRY
BRANCH
FRACTALIZE
MELT
MIRROR
STACK
CHAIN
SEGMENT
DIVIDE (ROUNDED: 1/2/3)
TRANSFORM INTO ANOTHER PRIMITIVE
CYLINDER:
1. EXPAND
1. NARROW
THICKEN WALLS
THIN WALLS
LATERAL SHOOT
VERTICA SHOOT
BEND
COIL
INFOLD WALLS
CRIMP WALLS
BIFURCATE
TRIFURCATE
TRANSPARENCY
BRANCH'S
SPIRAL
BUTTON + SYMMETRY
TRIANGULATE
FUSION INTO OTHER
MERGE
OVERLAY
ANTHROPOMORHIZE
CHANGE TOPOLOGY
GRID:
VARY HORIZONTAL LINES
VARY VERTICAL LINES
TRANSFORM OBLIQUELY
VARY SHAPE OF GRID
ADD SYMMETRY
ADD ANGLE
ROTATE
INVERT
ATTACH ROD STRAIGHT
ATTACH ROD BENDY
MULTIPLY
Cell behaviour
MULTIPLY
GENERATE NUCLEUS
DENT
BEGIN DIVIDE
CONTACT DIVIDE
DOUBLE CONTACT DIVIDE
BREAK ONE CONTACT JOINT
DOUBLE UP
BREAK ALONG ONE JOINT
TENDRIL AT BREAK END
ADD SEGMENTS CREATE INNER CIRCLE
SEGMENTS BECOME INNER WALL - SPAWN INSIDE
DENT - INNER CIRCL - SPAWN
OPTION: APPLY ACTION TO WHOLE FORM OR JUST PART OF FORM
ISOMORPHOLOGY
START:
SELECT PRIMITIV
SPEED:
ACCERLER
DECCELE
SCALE:
SMALL
MEDIUM
LARGE
TEXTURE:
ROUGH
SMOOTH
POUROUS
FEATHERED
FURRY
HAIRY
MATERIAL:
RIGID / ANGLES
FLEXIBLE / CURVES
NUMBE
1, 2, 3
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CHOOS
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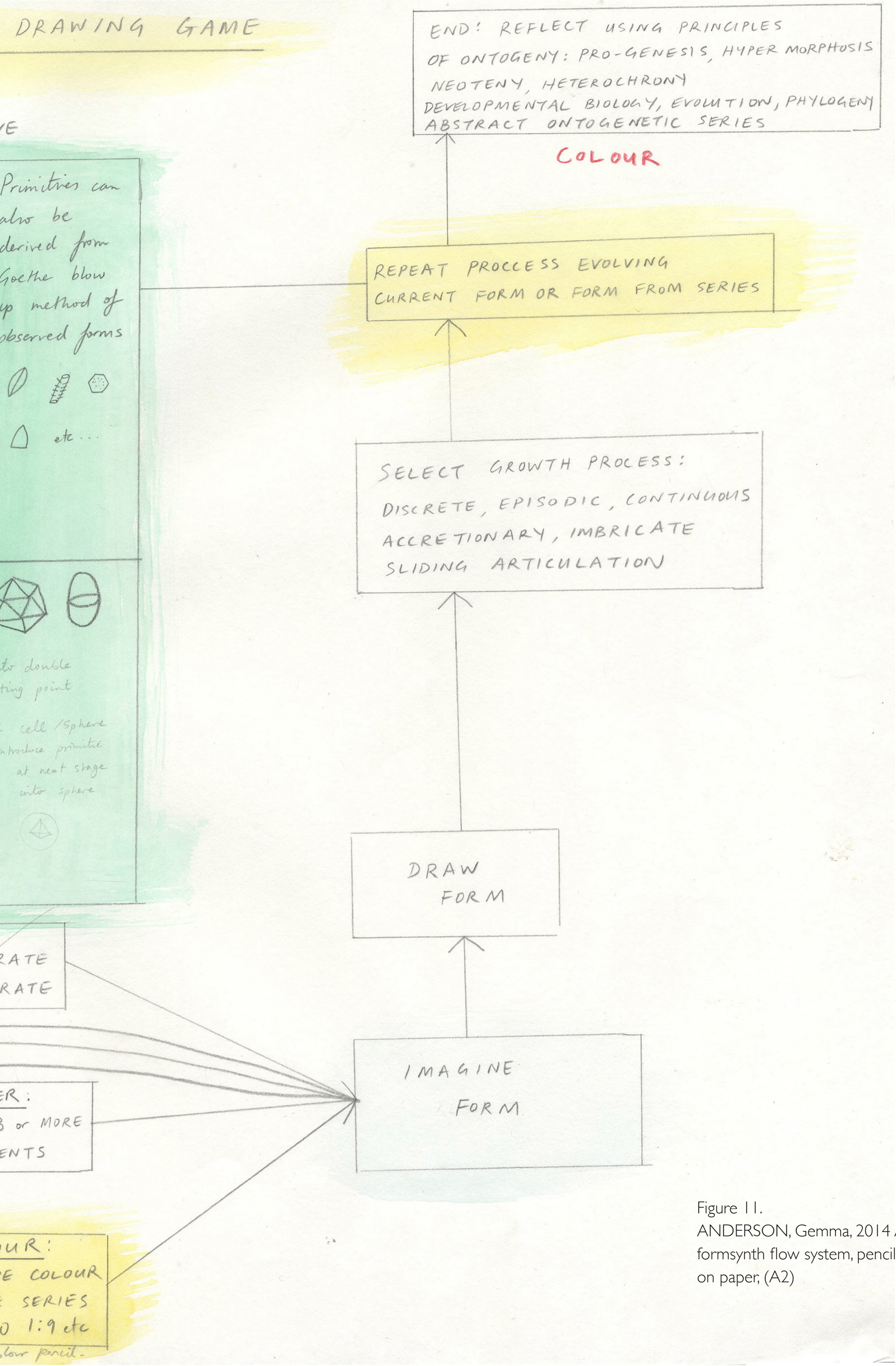

Figure 11.
ANDERSON, Gemma, 2014 Adapted formsynth flow system, pencil and watercolour on paper, (A2)

Klee's aesthetic influence is evident in Isomorphogenesis, which draws each stage in the development series as a connected continuum, rather than as isolated stages. Another significant influence from Klee is the application of his colour gradation method[24], which I have used to enhance the gradual nature of form change. Further to integrating these adaptations to the FormSynth system, I also decide to adjust how the method is 'played'. Instead of following the flow-system, I decide to organise the drawing actions into categories, which allows random selection to enter the process. This decision was based on an interest in relinquishing some of the decision making in the creative process and on encouraging an element of intrinsic surprise to enter the drawing process.
The influence of Isomorphology is clear through the exchange of Latham's group of primitives for the primitive forms of Isomorphology (See Appendix C.2 for details of Isomorphogenesis primitive forms). Another significant adaptation is the addition of primitive forms that are derived from observation[25], and which can be derived from practising the 'Goethe method' (see page 163)'.

The following text from my journal summarises the nature of the experiments[26] with the Isomorphogenesis method during a two-week residency in Cill Rialaig (2014) that resulted in the 'Isomorphogenesis series' and is followed by the full series of artworks:

> 'I started by experimenting with the Isomorphogenesis method (following adapted Flow System) and once I had evolved a few forms I tried marrying the evolved forms. I explored the colour gradation method using a background colour wash (Isomorphogenesis, no.3)(Fig.14). I began to experiment by introducing observational elements into the process (Isomorphogenesis, no.6)(Fig.17) and also took direct influence from the colours of the landscape around Cill Rialaig (Isomorphogenesis, no.4 and 14)(Fig.15 and 25) (shades of purple, grey, grey, yellow and brown). In response to preceding works (Isomorphogenesis, no.7) (Fig.18) I tried marrying forms at an early stage of development and then evolving descendants in two directions (I found this did not work so well: forms were not at such an interesting point at the marrying stage). I then experimented with two observational elements as starting points (Isomorphogenesis, no.8)(Fig.19) which introduced a new question to the process: how much detail to maintain and how much to generalize?

24 This method is described in the Klee chapter.

25 Allows observational details of colour, texture and variation on 'form species'

26 See appendix C.1.for full details of Isomorphogenesis process for works 4-14 and an outline of colour gradation method. Once proposed the Isomorphogenesis method had to be tested; the journal evidences this testing and how I came to evaluate the method.

Each drawing in the Isomorphogenesis series starts with a different combination of primitive form, for example, in Isomorphogenesis no.9 (Fig.20), I start with one abstract primitive and one observational element (Isomorphogenesis, no.9) this produces an interesting contrast and along with the choice of using observed or intuitive colours. I experiment with producing four descendants and I notice that I generally colour descendants in a pale shade of adult colour, like a young flower bud is paler in colour than the flower in bloom. I then experiment with evolving the same primitive through two different pathways (Isomorphogenesis, no.10) (Fig.21). This is an interesting exercise as they become quite different early on and are very distinct as adults. After, I experiment with evolving three observational forms simultaneously (Isomorphogenesis, no.11)(Fig.22). I select a rule and apply to the pathway that it seems to work with best, this stops me from getting stuck as rather than evolve one pathway and then evolve the next independently, I am evolving two or three at the same time and means that I rarely 'pass' an action (maybe a bit cramped on the small paper) I realize that each work feeds the experiments of the next, I will intuitively resolve what I want to experiment with in the next work. In Isomorphogenesis no.12 (Fig.23), I experiment with evolving two forms in opposite directions, which brings a flowing underwater feeling to the composition. I then evolve one form in a cycle (Isomorphogenesis, no.13)(Fig.24); interesting to see how much the form can evolve without introducing another adult and challenging to make a descendent from the features of one adult rather than two. This experiment made me think about different kinds of analogies these drawings make to asexual, heterosexual and homosexual reproduction' (Anderson, Journal, 2014).

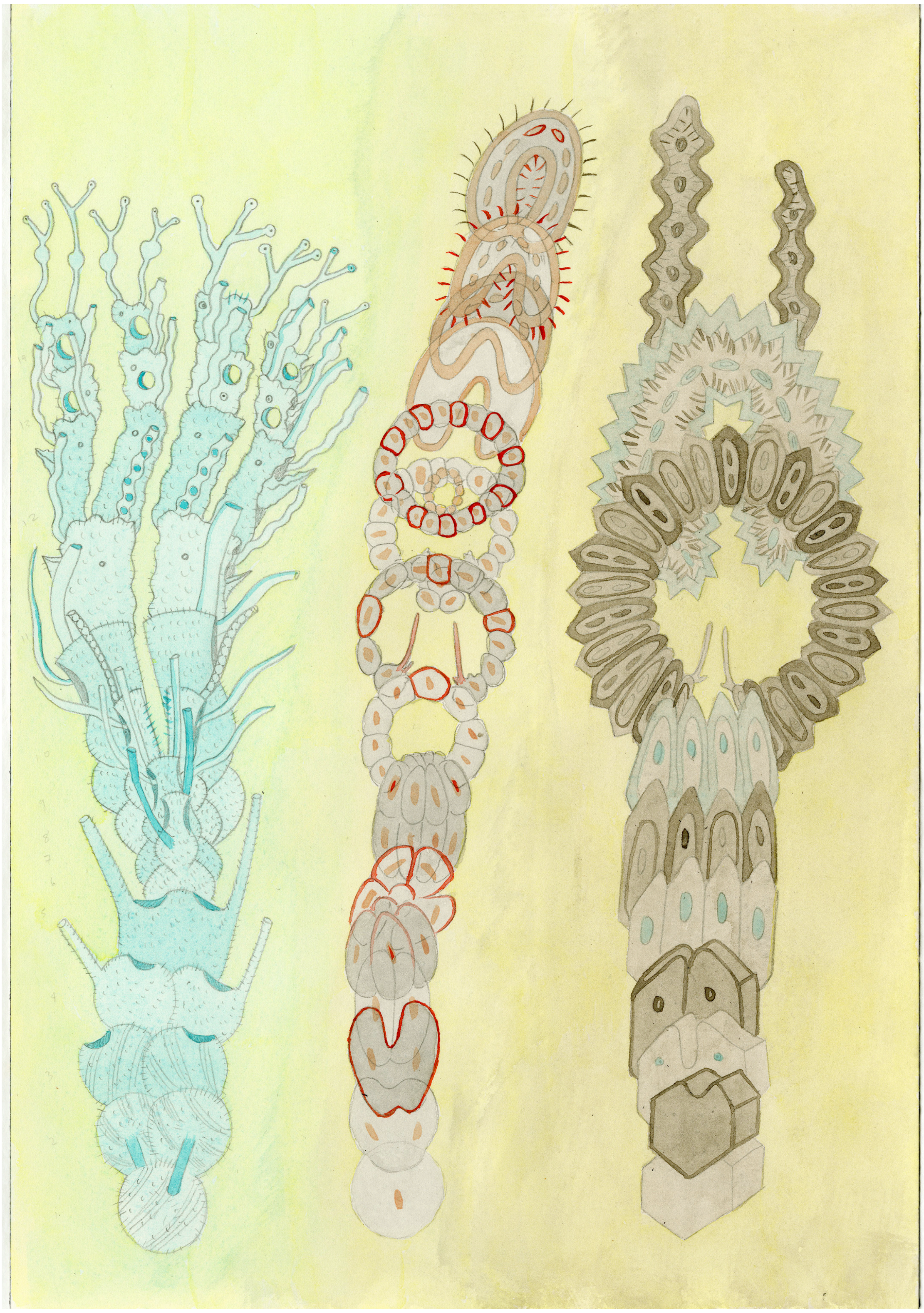

Figure 12.
ANDERSON, Gemma, 2014
Isomorphogenesis no.1, pencil and watercolour on paper.

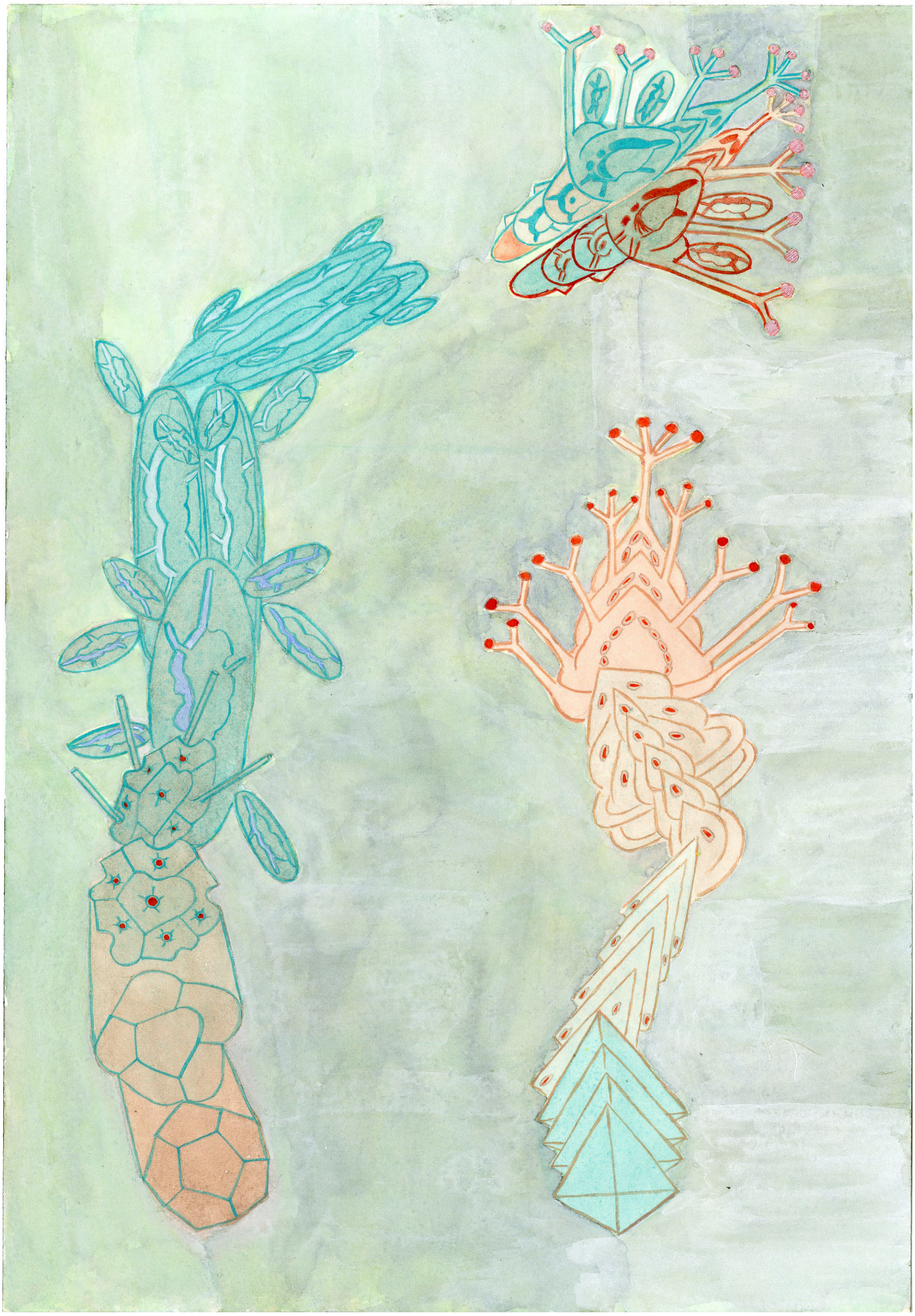

Figure 13.
ANDERSON, Gemma, 2014
Isomorphogenesis no.2 and no.14, pencil and watercolour on paper.

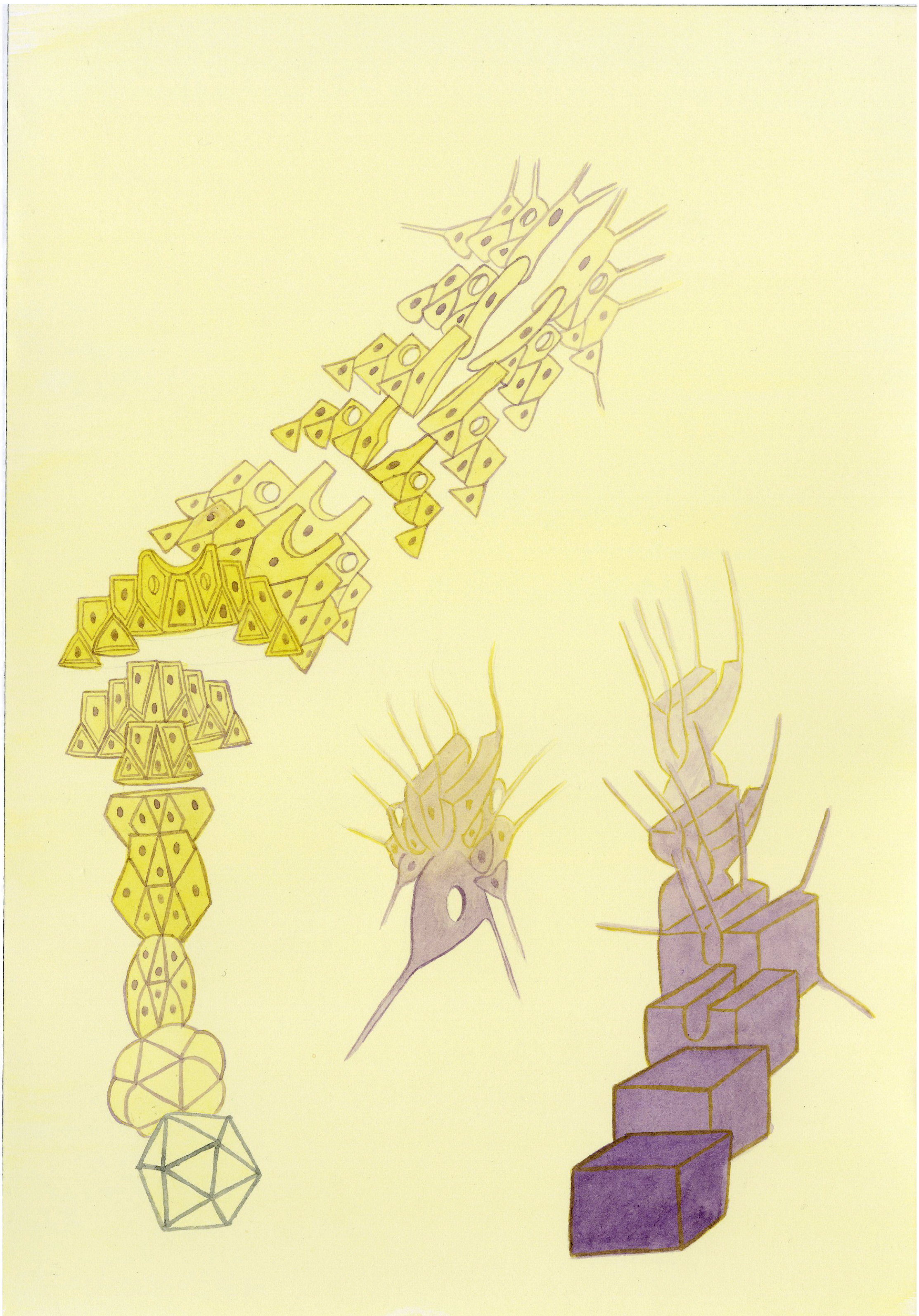

Figure 14.
ANDERSON, Gemma, 2014
Isomorphogenesis no.3, pencil and
watercolour on paper.

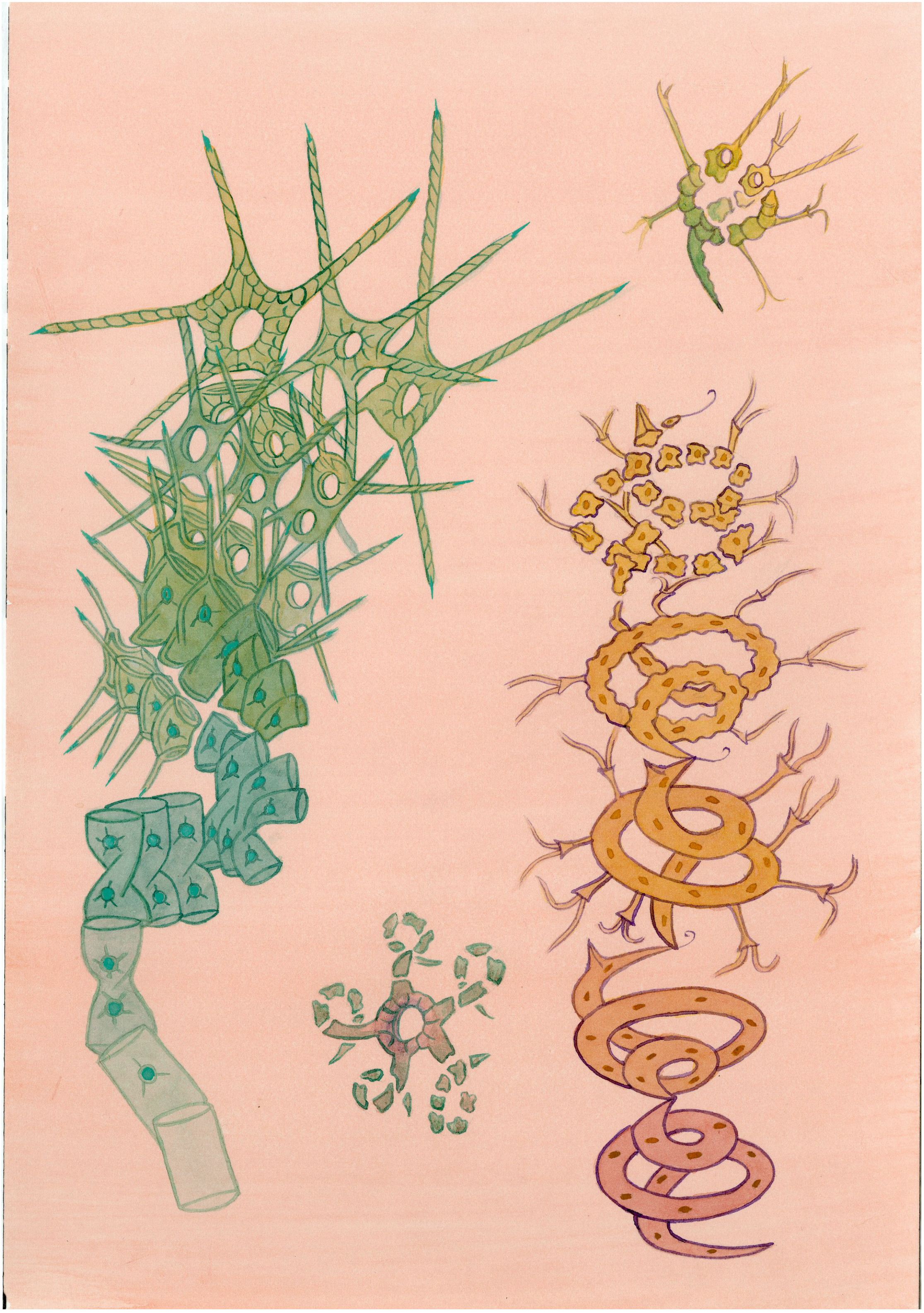

Figure 15.
ANDERSON, Gemma, 2014
Isomorphogenesis no.4, pencil and
watercolour on paper.

Figure 16.
ANDERSON, Gemma, 2014
Isomorphogenesis no.5, pencil and watercolour on paper.

Figure 17.
ANDERSON, Gemma, 2014
Isomorphogenesis no.6, pencil and watercolour on paper.

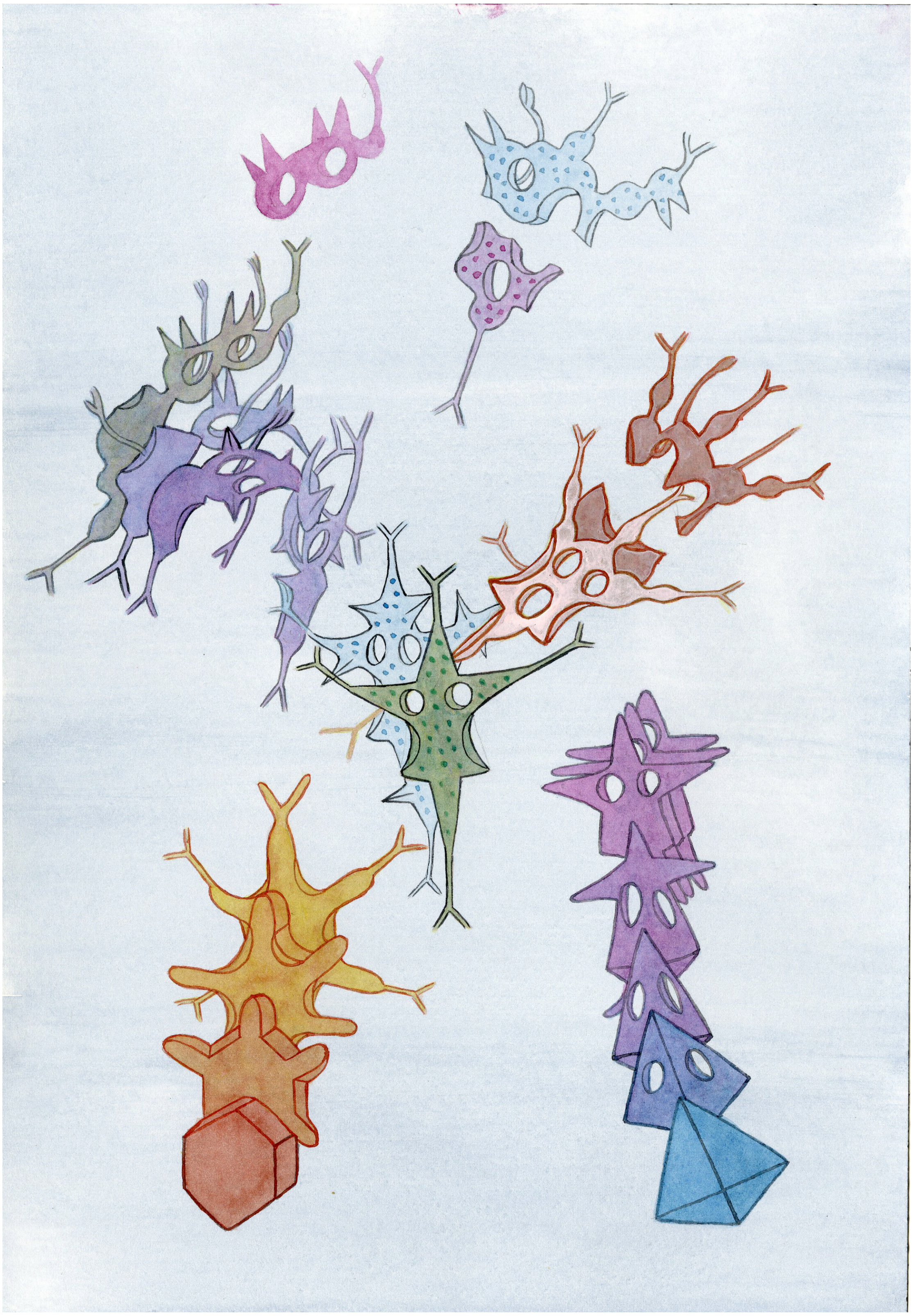

Figure 18.
ANDERSON, Gemma, 2014
Isomorphogenesis no.7, pencil and watercolour on paper.

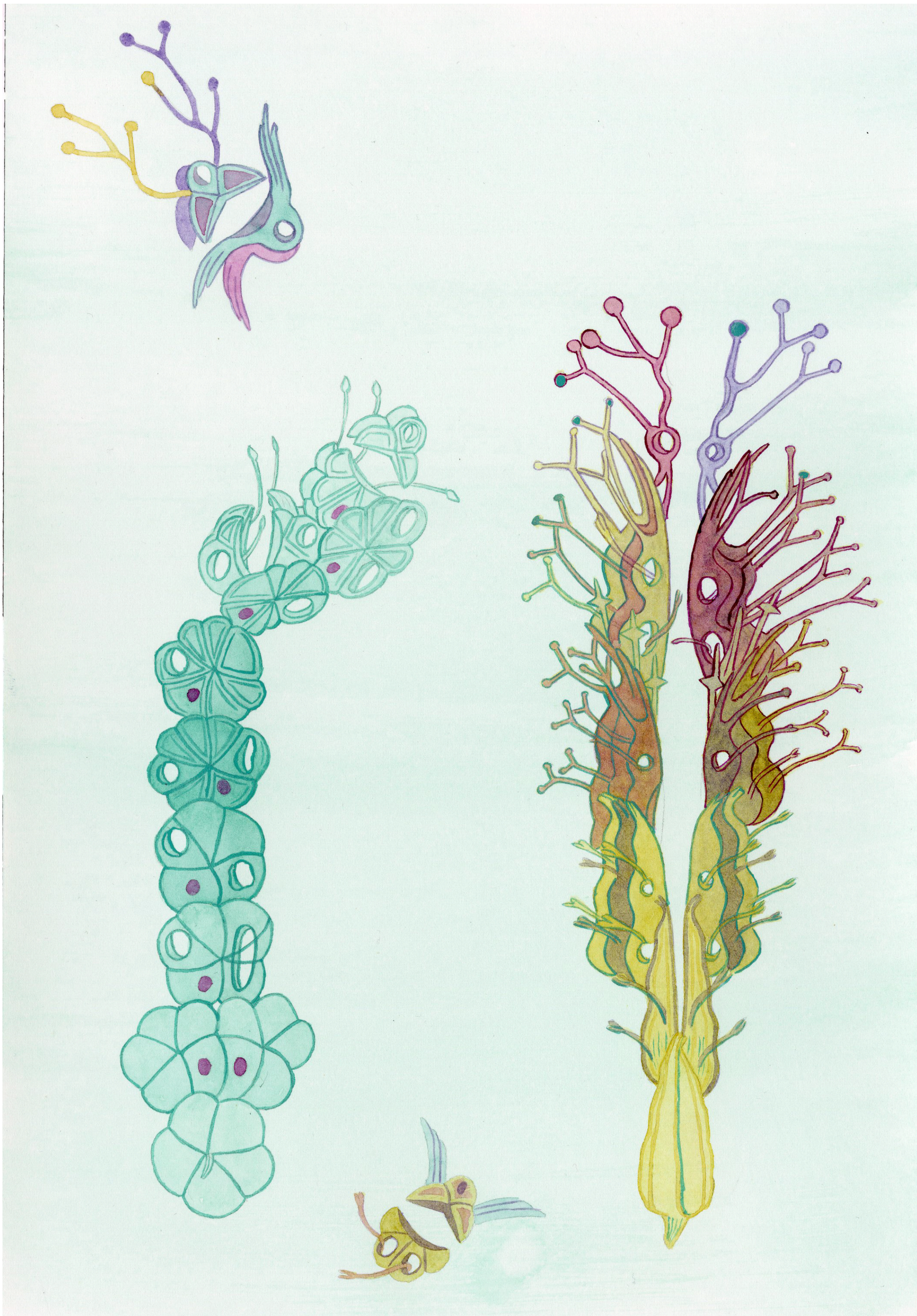

Figure 19.
ANDERSON, Gemma, 2014
Isomorphogenesis no.8, pencil and watercolour on paper.

Figure 20.
ANDERSON, Gemma, 2014
Isomorphogenesis no.9, pencil and watercolour on paper.

Figure 21.
ANDERSON, Gemma, 2014
Isomorphogenesis no.10, pencil and watercolour on paper.

Figure 22.
ANDERSON, 2014 Gemma,
Isomorphogenesis no.11, pencil and
watercolour on paper.

Figure 23.
ANDERSON, Gemma, 2014
Isomorphogenesis no.12, pencil and watercolour on paper.

Figure 24.
ANDERSON, Gemma, 2014
Isomorphogenesis no.13, pencil and watercolour on paper.

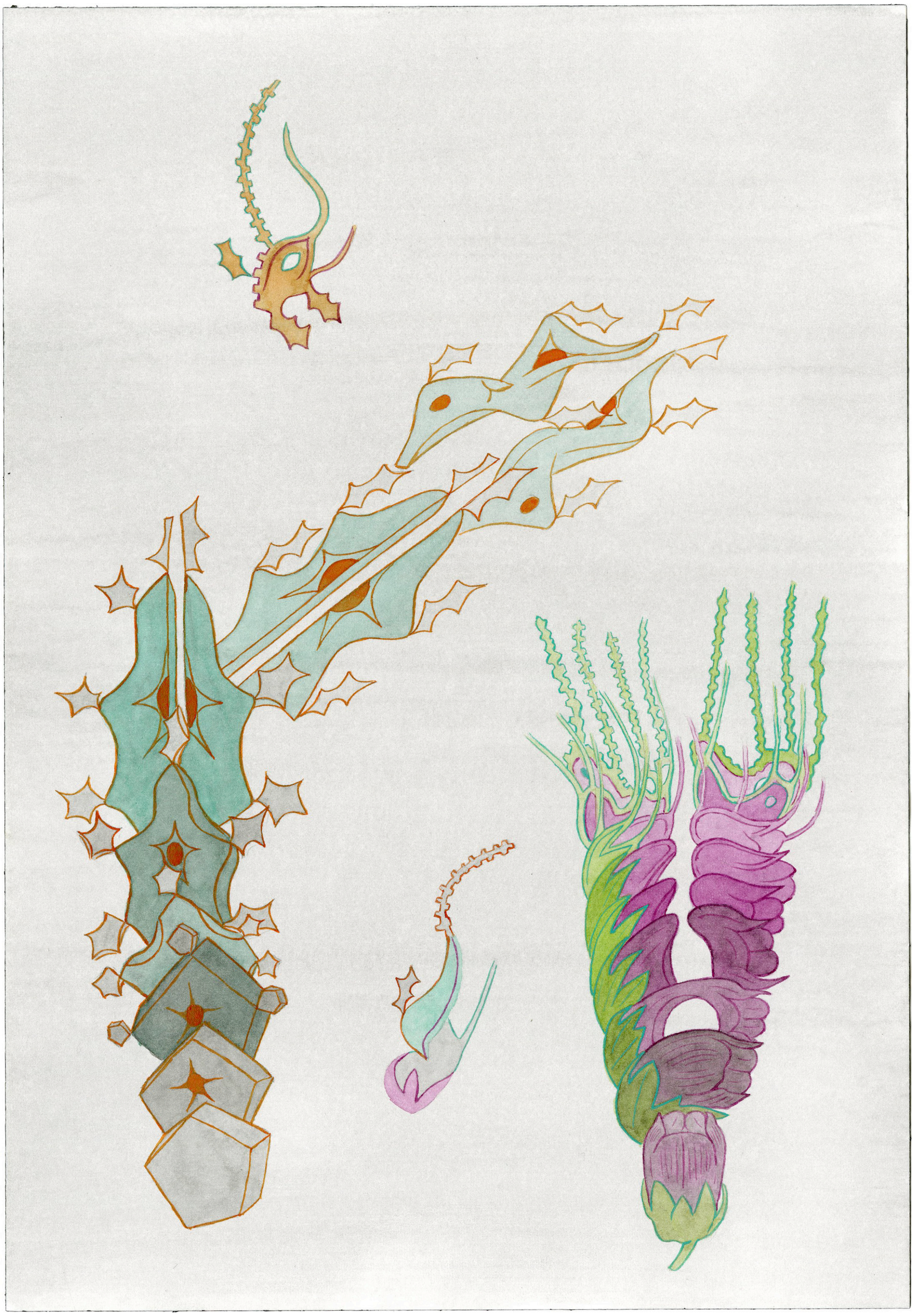

Figure 25.
ANDERSON, Gemma, 2014
Isomorphogenesis no.14, pencil and watercolour on paper.

After making these adaptations to Latham's *Formsynth*, I summarised the differences between 'Isomorphogenesis' and Latham's Formsynth as:

- The primitive forms of FormSynth are 'Euclidean primitives' (as defined by Latham, based on mathematical abstraction), whereas Isomorphogenesis starts with the primitive forms of Isomorphology (as defined by me), which are rooted in observation.
- Latham's FormSynth flow system produces a series of unconnected forms that show form development and are comparable to conventional scientific representations of ontogenetic series. After interpreting Klee's work as abstract ontogenetic series and working on the four dimensional tree, I could also see an opportunity to draw each stage of form development as a connected series, which is an unconventional approach.

-Latham's 'FormSynth' drawing method does not include an opportunity for observational input. Isomorphogenesis provides opportunity for observational

Figure 26.a.
ANDERSON, Gemma, 2014 Isomorphogenesis work in progress at Cill Rialaig, photograph.

Figure 26.b.
ANDERSON, Gemma, 2014
Isomorphogenesis work in progress at Cill Rialaig, photograph.

input through adding drawing 'actions' inspired by observation of plant growth, and through the option of beginning with a 'primitive' derived from the Goethe method.

-Latham's rules are derived from abstract ideas whereas Isomorphogenesis derived rules from scientific textbook images of cell development and verbs from botanical and biological textbooks (Hickey and King 2000 and Gilbert 1991) and from insight developed through attentive observation similar to the 'delicate empiricism' described in the earlier chapter five.

- Isomorphogenesis uses colour to emphasise the gradation of form, whereas FormSynth does not include colour.

- Isomorphogenesis selects drawing rules or 'actions' from a hat at random rather than following a flow system.

-Isomorphogenesis provides drawing actions in three distinctive hats (red for primitive forms, blue for actions associated with cellular growth and yellow for actions associated with later stages of development).

The Isomorphogenesis method explores working with parameters whilst allowing for creative input and involves analysis, intuition and improvisation. There are many aspects of the method where my adaptations expand the opportunities for decision-making in relation to the parameters more than FormSynth; for example, Isomorphogenesis allows for determining scale, orientation, composition and colour[27]. These decisions about colour, rotation, composition, where to begin and where to end, all work alongside the parameters of 'Isomorphogenesis'. Finally, and importantly, I allow the option to choose to not draw a particular iteration, to 'pass' the drawing action, which may be too difficult or counter-intuitive. This allows the drawer to make intuitive decisions while engaging with the Isomorphogenesis drawing process.

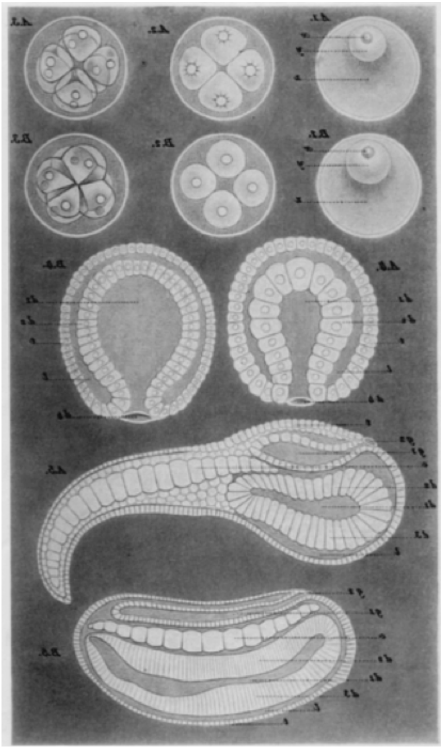

Figure 27.
UNKNOWN, Development of an embryo.
Welcome image collection.

Interpreting Isomorphogenesis

In the chapter six, I used the concept of an 'abstract ontogenetic, or developmental series' to interpret Klee's artistic representation of the dynamic nature of form. The Isomorphogenesis artworks 1-14 provide a new territory that explores the artistic representation of the dynamic nature of form to which I also apply an ontogenetic framework. I also interpret and further contextualise the works, returning to the biological concepts of TM and ontogeny and connecting to Dupré's work on a 'Process Philosophy of Biology'. Following this, I present an account of the dissemination of Isomorphogenesis through a number of public events and workshops, and I close the chapter by pointing towards further research.

Creating a set of parameters for drawing Isomorphogenesis provides its own conceptual 'growth rules' to simulate morphogenesis. There is a clear methodological parallel with

27 I chose to work with watercolours rather than etching for this practice as I wanted to work in a more immediate way. Watercolour is difficult to rework so there is a commitment and an energy that comes from having just one go at making the work.

TM here, which can be understood through McGhee's colleague De Renzi, who tells us that 'Theoretical Morphology searches for the essential geometric growth rules in any particular case' (1995: 241). An important difference is that computer simulated TM generates and values each growth stage numerically (and is therefore quantified), whereas in drawing, each stage will be valued on qualitative and aesthetic terms.

The biological concept of ontogeny and the scientific traditions of drawing and describing the 'ontogenetic series' that I previously applied to interpret Klee's work are useful in the interpretation of Isomorphogenesis. In terms of this research, the term ontogeny is used to refer to a developmental sequence of change in biological form. Figures twelve to twenty-five is based on the definition of ontogeny as: 'the conceptual and physical development of parts and the development of existing and known structures through actions which change the proportions and in the end create something new' (MacLeod, 2013, personal communication). More often than not, I rely on working definitions of scientific concepts, rather than textbook or encyclopedia definitions, which allow me to refer to concepts as they are defined by the field, rather than using de-contextualised definitions. This has been a positive outcome of the collaborations I have developed and has given a more genuine insight into scientific ideas.

Drawings of 'ontogenetic series' of embryo development first appeared at the beginning of the 19th century with the emergence of the discipline of comparative embryology. The contemporary developmental biologist Scott Gilbert tells us, 'The science of embryology is visual'. It is therefore difficult to conceive of an ontogenetic series without an image. Back in the nineteenth century, Haeckel used images to make arguments in his work in embryology (Hopwood, 2007). In the first images of a developmental or ontogenetic series (Fig.27) the development of form can be read like the lines in a book; for example, Haeckel's image of the uncleaved egg and its development to an adult-image proposes that 'epistemic virtues can be inscribed in images, in the ways they are made, used and defended against rivals' (Daston and Galison, 2007: 42). Haeckel described the value of drawing as a representation of development, describing his illustrations to show 'only the essentials of an object, leaving out the inessentials' (Haeckel, 1877: 858).

Isomorphogenesis builds on the aesthetics of ontogeny, especially those of visually sequencing development, but contributes by drawing development as a connected series rather than a series of instances as in Haeckel's imagery. The idea of representing development as a visual series has influenced the creation of my drawing methods. However, an ontogenetic or a developmental series is conventionally represented as a series of isolated instances (or slices of time) of form change when, in reality, transformation does not occur in isolated stages but in a continuum[28]. The intention of Isomorphogenesis is to create drawn ontogenetic sequences that show the development of form as a continuous process. Drawing is chosen to represent the development of biological form through an intrinsically connected image: A 'moving present'. In Isomorphogenesis, form change can be understood as a series of drawn 'movements', each defining a stage of development.

As well as images, the scientific concept of ontogeny offers a precise language to describe distinct types of development, including the following terms: pro genesis, hypermorphosis, acceleration, neoteny, heterochrony and allometry (Gould, 1977). MacLeod recognises that there are only a few scientists who understand these types of development other than evolutionary biologists, and that many evolutionary biologists do not learn these specific technical terms. The Isomorphogenesis method evolves form in a way that can be interpreted as analogous or consistent with these principles of ontogeny (biological development). I found the concepts of heterochrony, neoteny, progenesis, acceleration and hyper-morphosis helpful to understand and interpret the Isomorphogenesis series. For example, if we take Isomorphogenesis no.3 (Fig.14) as an example; the purple form on the right can be interpreted as an example of dwarfism, in comparison to the yellow form on the left, which has reached a more complex level of form evolution and can be understood as hypermorphosis.

As a simulation of development through drawing, Isomorphogenesis develops forms that exist as a variation of what is considered normal. Each evolution of form is imbued with the individuality of the drawing process, which is always a variation on the type. Each drawing evolves differently like each blade of grass grows differently, which adds further to the analogy of drawing to biological development. Each person practises the Isomorphogenesis method differently, performing variations on the theme, comparable to the variations on the type that we see in natural forms. In biological development, variations on the type can be considered 'normal' or 'abnormal', as can the 'Isomorphogenesis' drawings, which simulate forms that are similar but different to existent forms. Isomorphogenesis can therefore be understood as formal 'mutations' although this does not need to be a negative association. The potential to interpret the

28 E. Muybridge's human and animal locomotion photographic work is about movement rather than growth and development, but the issue is similar.

Isomorphogenesis series drawings based on biological principles of development reveals one way in which the drawing process developed my insight into and understanding of biological principles, as well as the educational potential for practising this method within a scientific context.

<u>Sharing Isomorphogenesis</u>

I began to develop the Isomorphogenesis method into a workshop to explore whether the ideas and approaches could transfer to practice and theory in both artistic and scientific contexts. I chose to deliver Isomorphogenesis in the following ways: I organised a collaborative workshop with William Latham at the Natural History Museum and I integrated Isomorphogenesis into a three-day workshop at the St Ives School of Painting which included Isomorphology, Goethe and Isomorphogenesis (September 2014 and May 2015).

Reflecting on delivering these workshops, combined with my own experience of practice, helped me to understand and summarise the 'Isomorphogenesis' method into the following steps:

1. Prepare paper with translucent watercolour background (optional).
2. Draw a three-dimensional primitive form. This can be a three-dimensional 'form species' of Isomorphology (as selected from an action/drawing in the red hat), a three dimensional 'character' derived from the Goethe method, or a three dimensional form drawn from nature (field work or museum specimen) or art[29].
3. Apply a drawing action, selected from a hat, to the primitive form. This action is drawn as a repetition of the previous form with the drawing action applied and as a connected drawing to the previous stage (not like traditional developmental series where form is disconnected).
Select drawing action from flow system or blue hat (primitive) and apply action to primitive form.
4. Select drawing action from yellow hat (less primitive) and apply action to primitive form.
5. Select drawing action from yellow hat (less primitive) and apply action to primitive form[30].

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29 For example Barbara Hepworth Sculptures, which we drew from as part of the St Ives School of Painting Isomorphogenesis workshop.

30 The amount of times that an action is selected from the yellow hat is optional.

6. Keep going with yellow and blue until form is too complex to continue or decide that form is evolved - as an 'adult' (It is also possible to inverse from adult to primitive: a kind of decay, or deformation).
7. When one form has been evolved to an 'adult' form, begin to evolve another form in the same way.
8. When the second form has evolved to an adult, decide to either marry the two adult forms or evolve another (this may depend on how much space is available on the page).
9. Evolve the married progeny by applying drawing actions (just as with the initial primitive form) or begin to evolve another form.
10. Apply Klee's colour gradation method (this is difficult and often mistakes become features which can help to maintain the individual character of the work).
11. Continue the process, making decisions based on what has been explored in first experiments (as exemplified in my own extended exploration of the method discussed earlier in this chapter). For example, the choice of the next primitive might be based on choosing two of the same form or two different forms, one abstract and one observed, or one from art and one from nature (see page 157)

NHM Isomorphogenesis Workshop

I invited William Latham to collaborate on an 'Isomorphogenesis' workshop which I had organised at the Natural History Museum as part of THE BIG DRAW 2014(Fig.28). This collaborative workshop provided an opportunity to share and to compare my own ideas with Latham's and to bring our experimental drawing methods together, inviting members of the public and scientists to participate in both creative processes and to share an understanding of their inspiration (details of these workshops can be found in Appendix C.3). The following text is an excerpt from a blogpost about this collaborative workshop published on the NHM Nature Plus website (Anderson and Freeborn, 2014) and on the Big Draw and Campaign for Drawing blog, (Anderson, 2014b).

Sunday the 19th October 2014

11am - The group (mathematicians, psychiatrists, RCA students, NHM scientists and the editor of New Scientist) arrives at the Angela Marmot Centre (NHM, Darwin Centre). We introduced ourselves and the workshop and Gavin Broad (NHM Zoologist) gave an introduction to handling the collections followed by a tour of the hymenoptera collections. We discuss how the collections are classified and new species described. I also provided the audience with details of my collaboration with Broad including the different questions and approaches involved in our research with the museum collections. I then introduced the concept and practice of 'Isomorphology' as an

Figure 28.
ANDERSON, Gemma. 2014. Photographs of workshop in collaboration with Latham at the Natural History Museum.

alternative approach to classifying the collections and reported on different ways of knowing in artistic and scientific fieldwork. The tour ends with a general discussion and the group asks interesting questions about ways of describing and naming new species. One participant reflected on this part of the workshop through feedback: 'Gemma and Gavin worked very well together to engage the group- this day will be very memorable!' (BA Hons Drawing Graduate)

11.30am – The group returns to the AMC workshop area and each participant is asked to choose a specimen that he/she would like to draw. I explain that the specimens had been loaned by curators as they are specimens that have interesting morphology and have been included as part of the Isomorphology study.

I then introduce the Goethe drawing method, which expands and transfers Goethe's concept of 'delicate empiricism' through drawing as a way of getting to know the specimens and sourcing the 'primitives' for Isomorphogenesis. The participants observe, write, draw from observation, draw from memory and then imagine expanding the specimen into component parts, which is important for the starting point for the afternoon drawing session when we deduce a primitive form from observation and take that as a beginning form to evolve through the Isomorphogenesis drawing system. Gavin Broad, reflected on this stage of the workshop: 'I found myself understanding the recurrent forms of the natural world through drawing, which enabled me to break down shapes into component parts'.

12.15- Latham introduces the background and context of FormSynth and demonstrates the FormSynth drawing system to the group. The group is then asked to practice the rules and to add their own rule.

2pm - I introduce Isomorphogenesis as an evolved adaptation of Latham's FormSynth. I explain how I have introduced rules/parameters to the system, which are derived directly from my own observations of cell development and plant growth and which continually relate the drawer back to the natural world. This process began by selecting a primitive from the Isomorphology 'form species' as well as primitives sourced from NHM specimens following the Goethe Method. The group then evolves the forms by randomly selecting a drawing 'rule' from a hat, which I offer while circulating the room, which provides an opportunity for assisting and answering individual questions. The editor of New Scientist, Sumit Paul-Choudhury, reflected on this part of the workshop: 'The randomized selection of a mutation (drawing action) to use was a challenge and a novelty each time. This was the part of the process that was most fertile in terms of understanding the resonances between artistic practice and scientific or observational methods'.

I ask the group to draw form change in a connected series, based on the understanding that biological growth occurs in reality as connected transformation, not isolated as stages, as commonly represented in scientific representations of ontogenetic series. I continually encourage the group to refer back to the specimen and to include these observational details intermittently throughout the drawing process.

When the group has evolved a number of primitives, I ask them to think about marrying forms, while maintaining the general characteristics of each adult to make one or more progeny. This is something that both Latham and I consider the act of drawing can do more successfully than computers. A masters student from the Royal College of Art reflected on this stage: 'When marrying forms to create new mutations of the previous form, my imagination could flow freely with the natural set of rules'.

The workshop ends with some reflection and discussion of the day's drawing methods. My collaborator Alessio Corti (Professor of Mathematics at Imperial College), who joined the workshop, asks a question about the possibility of different types of drawing systems as analogous to new species and the other participants offer thoughts on different possibilities of generative systems and ways in which we could begin to think about their classification. At this point Gavin and I discuss how aspects of the methodology employed during our workshop are similar to the work of the NHM scientist. Another RCA MA Printmaking student reflected on what she learnt, which Gavin agreed as helpful in both artistic and scientific study: 'I gained a new knowledge that the natural world is made up of a set of forms that repeat themselves in different ways - seeing the object as a whole but also as its component parts - writing descriptively and creatively about the specimen was helpful and a new way of verbally drawing'.

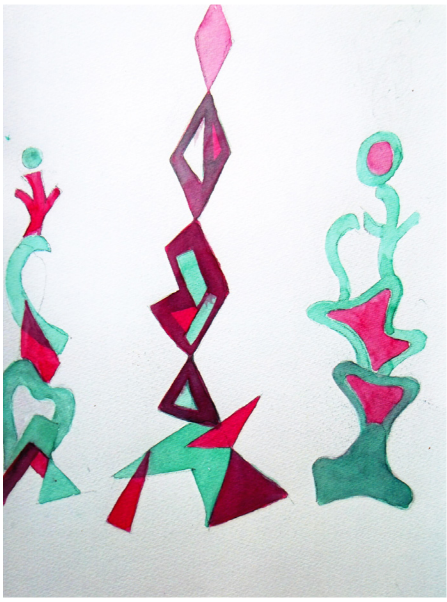

Figure 29.a.
ANDERSON, Gemma. 2014. Photographs of artworks produced at St.Ives workshop
Figure 29.b.
ANDERSON, Gemma. 2014. Photographs of workshop process at St Ives School of Painting.

St Ives School of Painting workshop

This three-day workshop[31] integrated the Isomorphology, Goethe and Isomorphogenesis methods and includes fieldwork, museum visits and the loan of museum specimens from The University of Exeter. For the purpose of this chapter I will only discuss the third day, which focused on the Isomorphogenesis method(Fig.29). The following text acts as a report on the activity of the day.

The group of ten participants included a journalist, two head-teachers, two art teachers, an NHS administrator (who had previously trained as a botanist), an environmental scientist, a therapist (who was also a musician), a science teacher (who was also an amateur artist) and an engineer (who had trained as a marine biologist).

Wednesday 13th May 2015

On the third day of this workshop, our experience of drawing the Isomorphology forms as three-dimensional and two-dimensional is helpful as is the drawing and thinking about morphological characters' possible combinations as practised, which triggers questions about formative process through the Goethe Method (on day two). We then progress to gain insight into formative process through practising the 'Isomorphogenesis' drawing method. I began with an introduction to the Isomorphogenesis method (following the logic of this chapter). We began 'Isomorphogenesis' by drawing the abstract forms and symmetries of Isomorphology in three dimensions, which is aided by our drawings from

31 Held in September 2014 and May 2015

the day before of the Hepworth sculptures where we focused on topology and drawing three-dimensional form[32].

The following quotes describe how the context of the Hepworth gardens enhanced the drawing process:

> I made the conceptual leap from observation to abstraction after the Hepworth garden study. After that, the recombining concept was easy to understand and follow (Designer).

> Fascinating and logical. I love the way the stages built on each other (Artist).

We evolved our 'primitive' forms (which we chose from Isomorphology form species, Goethe method character or observational element) through applying drawing actions as selected from the hat I pass around (as in the NHM workshop). I then walk around and ask each participant to choose an action (blue first) from the hat; as at the NHM workshop walking round allowed me to help address individual questions and to help each participant grasp the process.

> Understandable, logical and interesting [...] the labels in hats was a very useful idea (ex-teacher).

I explained that the Isomorphogenesis method is not a 'true' analogue of how things grow as it does not include external environmental (abiotic) factors (which is one of the areas where this method can develop) but it does give us insight into the gradual nature of form change, through drawing practice. There are also differences between a pencil line and a cell lineage, but the aim is to create a kind of analogy or isomorphism, not a realistic representation.

> I like the whole concept of the conceptual forms abstracted from nature and evolving them. It made me look at all natural forms in formation format. Example, I do not just see nice flower but the symmetry formation of the flower, etc' (Jewellery Designer).

32 I encouraged the group's attention to the three dimensional qualities of Hepworth's abstract sculptures and referred back to Goethe's ideas about art aiding observations of natural form. This exercise helped participants to think about 'topology' and how piercing a form changes the nature of the three dimensional surface.

Rather we are simulating an analogue of biological development through drawing. Each person interpreted the rules slightly differently, which was interesting and part of the human feedback and contribution to this analogy. We then apply the Paul Klee's colour gradation method (see Appendix C.4) to our drawings, which I discuss as 'abstract ontogenetic series'.

I then asked participants to create their own drawing actions[33]. The possibility for participants to feed back into the method by generating their own rules encourages active engagement and allows for an open ended creative practice that can evolve in many directions. I then integrated some of these rules into the Isomorphogenesis method by adding the new rules on a piece of paper to the blue and yellow hat (see Appendix C.5). The workshop cultivated an atmosphere of creativity and joy, which one participant found rewarding:

> 'The sense of interconnectedness has been experienced by simply observing describing and evidencing – moving into Isomorphogenesis of making something that did not previously exist is deeply satisfying' (Art student).

The teachers and ex-teachers who attended the course gave feedback that they thought the method would be useful in art education. One teacher commented that it would be a great way to get kids to think about science and art together and to use their imaginations (commenting that the school curriculum does not provide enough space for the imagination):

> As a scientist and artist I enjoyed the course and it gave me the time and space to play which is massively important to me …. as a trainer and someone who trains people to train I went away thinking of lots of ideas (Science teacher).

The group produced the following images, which provide evidence or their grasp of the method (See Appendix C.6).

33 Rules: Squeeze, Invert- beak into rather than out of form, bend/dodge, apply spiral, segment, add shadow, rotate (to any angle), join ends, change scale of element, jigsaw cast, merge – join, adjoin, connector- plug, rotational symmetry)add beak on opposite mirror side, triangulate, texturalize, expand in space, elongate, layer/gradient, repeat, oblique-leaning etc.

Overall reflections on workshop practice

The use of images to communicate the concepts of the ontogenetic series in relation to biological growth and plant growth helped to encourage the possibility of drawing to simulate development through the Isomorphogenesis method.

Isomorphogenesis provides drawing actions in three hats: red for primitive forms, blue for actions classified as more cellular and yellow for later in development. Picking drawing actions at random from a hat, rather than following a flow system, allows for chance and a renunciation of decision-making. It also allows the opportunity to discuss the process discretely with each individual as I bring the hat around the group. To explain the role of parameters in creativity I have found helpful to relate to something simple, like describing how a recipe for cooking establishes parameters and can be understood as a form of algorithm. This helped participants to grasp complex ideas, and was reflected in the feedback of one: 'Gemma was able to deliver a difficult concept in easy stages' (Artist). Using a hat rather than asking participants to make their own decisions about which drawing action to select and apply has shown to provide creative challenges for participants. This is an important epistemological reason for using the hat: It motivates the introduction of the chance element into the process.

Isomorphogenesis demands that each stage is drawn as a modification and connected continuation of the previous stage. This can take a few attempts to understand. I have found it has been helpful to respond to questions through drawing with participants. People often ask 'how do I know when to stop?' and I suggest to make the decision intuitively, possibly influenced by the difficulty of applying the action or that the drawing becomes restricted by the scale of the page. The parameters of Isomorphogenesis allow for imagination, intuition and observation through maintaining a good level of structure, control and freedom to experiment.

Visualising and drawing the form species of Isomorphology in 3D without an observational reference point is conceptually and technically challenging; one participant described 'trying to draw the evolved forms and incorporate the new instruction (picked-out from the hat) because the technical aspect of drawing something from 2D into 3D is a challenge to me'. I have also found it challenging to visualise and draw in three dimensions without an observational reference point, which is why I decided to bring participants to draw from Hepworth's sculptures to provide another source of abstract three-dimensional forms as starting points. There is a natural tendency amongst participants to draw in two dimensions when there is no observational reference point, but I emphasise drawing and visualising in 3D as it provides a closer analogue for biological development.

The workshops demanded my full interaction during the entire process. It has been important to respond to the questions of each individual to support their understanding of the method, and giving my full attention maintained a good level of concentration and interest amongst the group. Isomorphogenesis provides a guided method for intellectual and artistic creativity to combine: 'this course has been the best course I have ever attended! It's mind blowing- the creative practical work has and will assist my personal development and has enhanced my identity as a human being. I can see that I can apply the methods to my art practice and my life in general' (mature art student).

The challenging nature of these workshops, combined with practising a new method, has brought enjoyment of both the intellectual and the artistic simultaneously and has proved to be effective in generating new ideas in relation to the participants' existing practice. One participant 'enjoyed thinking through the evolution of form, it was challenging and interesting', while the following feedback reflects how practising Isomorphogenesis can feed individual creative work:

> The method may help me to develop some ideas I have been working on as a kind of 'framework' to developing new forms. I liked the introduction of scientific terms as the course has helped me to visualise what they could mean eg- mirror, bifurcate, multiply and slice, and how to incorporate them through drawing. (Artist)
>
> 'This method helps to expand the artist mind and explored different ways to interpret the natural forms. I learnt all natural form can be view in the Isomorphic classification and evolve format and hope to bring this into other aspects of my art work' (Designer).

<u>Isomorphogenesis builds on Isomorphology and Goethe method</u>

The experience of delivering Isomorphogenesis as an independent workshop and as the third day of a workshop series has allowed me to reflect on how Isomorphogenesis developed from and builds on these other methods.

The Isomorphology and Goethe inspired drawing method share with Isomorphogenesis the exploration of drawing as epistemology for morphology through establishing parameters and guidance for a thoughtful, productive and insightful creativity.

Isomorphogenesis provides an evolution of both the Isomorphology and the Goethe method by offering the option to begin with a form species of Isomorphology or a morphological form element derived from the Goethe method. The 'Goethe' method, which itself evolved out of the Isomorphology practice, provides a way to obtain primitive forms or 'form species' from complex natural forms which can function as an observational starting point for the Isomorphogenesis method. Starting with an observational element enriches the aesthetics of the work through providing details of form, colour and texture. The option to work from the 'form species' of Isomorphology or from those of the Goethe method makes Isomorphogenesis a method which can be practised in the field or the studio.

The Isomorphogenesis method enables a simulation of the development of each form through a series of drawing actions and decisions (either through following the hat method or the paper flow system). As such, Isomorphogenesis integrates aspects of the Isomorphology and Goethe method into a drawing method that moves further away from observation towards a conceptual representation of the dynamic nature of form.

Conclusion

In order to represent morphology as dynamic and formative in nature, it is necessary to visualize and make evident the change before and after it occurs. Through drawing, it is possible to slow a formative process down to a series of connected images, a developmental series. Human understanding requires comparison and a drawn representation of development as a connected continuum enables the drawer and the viewer to see form change in stages simultaneously. This has an epistemological advantage over a seamless animation, which does not reveal discrete stages for comparison.

Isomorphogenesis requires engagement at every stage throughout the whole drawing process, whereas computerised simulations of form are given parameters and then automatically run these to see what is produced. Current visualisations of biological processes exist mainly as computer or digital images or animations[34], which only allow the viewer a way to witness knowledge rather than a way to own knowledge. The non-mechanistic and embodied drawing process is a way through which knowledge can be both created and owned because participation is necessary at every stage. The requirement to perform a movement or 'action' of biological process means that

34 As for example at the Coen Lab (Coen, 05/07/15)

understanding is also favoured at every stage. Drawing can therefore elaborate a view of multiple developmental stages simultaneously as an accumulation of knowing through action, which holds epistemological value.

Presenting Isomorphogenesis to others as a model and method, which simulates an analogy with biological development, has shown potential for the method to transfer in an academic and non-academic context. The Isomorphogenesis method offers a non-trivial way for scientists and artists to creatively engage with the concept of development through a method that is both artistically and intellectually stimulating. The Isomorphogenesis artworks have been valued as representations of the dynamic nature of form within the field of 'Process Biology' as they provide new analogies and metaphors for thinking. In academic contexts, they have been exhibited at the University of Exeter's 'Process Philosophy of Biology' conference (organised by Dupré, November 2014). The Isomorphogenesis series has also been part of 'Crooked Rain, Crooked Rain', an exhibition at the Centre for Contemporary Art, Derry (February-March, 2015). I have presented this research at the International Word and Image Society conference 'Riddles of Form' (directly inspired by *On Growth and Form*) at Dundee University (August 2014) and the solo exhibition 'Drawn Investigations from Art and Science' at Queens University Belfast (February-March, 2016). Beyond this, I have explored possibilities of how the Isomorphogenesis method could transfer to sound with Dr Gascia Ouzounian (Senior Lecturer, Queens University) and Dr Federico Rueben (Senior Lecturer, York University), dance with Katrina Brown (Senior Lecturer, Falmouth University) and gaming with Professor Simon Colton (Falmouth University) but these ideas are themselves in an embryonic stage. Although it has not been possible to realise all of these ideas as of yet, there is potential along a number of avenues.

Isomorphogenesis has enriched my own understanding of the dynamic nature of form. The practise of artistic experiments, which draw from the influences described in this chapter, has resulted in a method which is satisfying both intellectually and aesthetically. Like theoretical morphology, Isomorphogenesis generates theoretical forms that cannot be found in the natural world, but are derived from an empirical and conceptual understanding of form and therefore provide great opportunities for creative work, both artistic and scientific.

Chapter Nine

The Cornwall Morphology and Drawing Centre

The experience of working in both artistic and scientific contexts has led me to develop the 'Cornwall Morphology and Drawing Centre' (CMADC), a space that brings practices, questions, knowledge and objects of art and science together. CMADC has provided a live testing ground for sharing my own drawing practices of Isomorphology, the Goethe drawing method, and Isomorphogenesis with the public and is an important outcome of this research and artistic practice[1]. In this respect, CMADC contributes to contemporary practices that consider artwork as an educational medium, as associated with the 'Educational Turn'[2].

Background

Cornwall offers an outstanding biodiversity largely due to the temperate oceanic climate, geological phenomena such as the Ophiolite Lizard Serpentine peninsula, sub-tropical gardens and the history of mining[3]. This rich diversity of natural forms has sustained my own study of morphology and has fuelled a long history of the study of the natural world in Cornwall, which is reflected in the county's polytechnic societies[4] and museum collections[5]. Cornwall is also home to an increasing number of art and science academics, due to the presence of Falmouth and Exeter Universities, which is complemented by a culture of natural science societies and artists' studio groups[6].

Against this background The Cornubian Arts & Science Trust (CAST), an educational charity, was inaugurated in 2012:

> CAST works with artists, curators, writers and specialists from other fields, locally, regionally, nationally and internationally, to develop professional expertise and exchange, to present examples of outstanding creative practice, and to create opportunities for audiences of all ages to experience ground-breaking cultural activity (CAST, 05/07/15).

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1 CMADC is presented through this chapter, Appendix D and a website archive.
2 The term 'educational turn' was coined by Mike Wilson and Paul O'Neill in 2010.
3 Mining (to some extent) prevented agricultural development and allowed plant diversity to be maintained.
4 For example, The Cornwall Botanical Society, Microscopy Society, Astronomy Society and Mineral Society amongst others.
5 For example, the Rashleigh and Williams Mineral Collections at the Royal Cornwall Museum and Caerhays Castle.
6 For example, Cornwall Botanical Group, Cornwall Astronomical Society, Cornubian Art and Science Trust, Porthmeor Studios amongst others.

CAST, an artists' studio complex and project space is led by Teresa Gleadowe, who previously developed The Falmouth Convention[7] that placed experiential fieldtrips at the centre of the discussion. The subsequent Penzance Convention[8], brought the theme of extraction to a series of fieldtrips that included art/science collaborative projects with Camborne School of Mines, and explored Cornwall's other 'extractive' industries – farming and fishing. CAST is based in an old 'School of Science and Art' building in Helston, located between two areas of outstanding natural beauty: the Lizard and West Penwith. The aims of CAST and the history of the building inspired the CMADC project idea, which I proposed to Teresa Gleadowe in September 2014. The project began in December 2014 with the help of funding from Falmouth University's Research and Innovation Fund.

Cornwall Morphology and Drawing Centre

The aim of CMADC is to use drawing as the primary mode of investigation for participants to learn about morphology: animal, mineral and vegetable. Learning takes place through a series of collaborative drawing workshops[9] with scientists from botany, mineralogy and zoology to mathematics, to identify and address questions that concern scientific and artistic practice. Each workshop offers a unique drawing method through which participants can focus and engage with a range of subjects:

- *The Isomorphology of the Lizard* (In collaboration with a Botanical Scientist)
- *Drawing in the Fourth Spatial Dimension* (In collaboration with a Mathematician)
- *Drawing the Six Crystal Systems* (In collaboration with a Mineralogist)
- *The Art and Science of Systematics* (In collaboration with a Zoologist)

These workshops build on the drawing methods developed in the Isomorphology, Goethe and Isomorphogenesis studies by acknowledging the participants' ability to co-create knowledge, through sharing questions that run through and alongside my artistic research. This approach reveals the methods of my own artistic practice and allows the

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7 The Falmouth Convention was a three-day conference in unconventional form, with an emphasis on exchange of views and experiences. Conceived as an international meeting of artists, curators and writers to explore the significance of time and place in relation to contemporary art and exhibition making, it was planned to respond to the situation in Cornwall and other such dispersed, rural areas (Falmouth Convention, 2010).

8 Building on the legacy of The Falmouth Convention, The Penzance Convention was a three-day conference in expanded form. It reflected on the theme of extraction, with reference both to the social and environmental narratives of Cornwall's extractive industries – mining and fishing in particular – and to the processes by which artists draw meaning from history and site (Penzance Convention, 2012).

9 These workshops have emerged as the result of long-standing collaborations I have developed and sustained throughout this research.

participants to create their own knowledge about the morphological subject. The 'art' is therefore partly located within the transformation that occurs in this shared learning through artistic practice and leads to a change in the participants' engagement[10] with morphology.

The use of activities within each workshop such as talks, fieldwork and discussions expands the notion of the educational potential of art in the context of CAST. As a combined studio and learning space(Fig.1) CMADC offers insight into my own artistic and collaborative process whilst also inviting participants to take an active role in the process of artistic enquiry. Kenna Hernly, a learning curator at Tate St.Ives, reflected on this 'learning by doing' aspect of CMADC in her review of the project on the BIG DRAW website:

> With learning as a central goal, the Cornwall Morphology and Drawing Centre holds huge potential by offering participants the chance to improve drawing and observation skills while learning about plant and mineral morphology. What is so unique is that these learning activities are central to Anderson's practice as an artist; every participant is offered the opportunity to make an active contribution to the new study of Isomorphology, which provides endless opportunities to study shared forms in nature (Hernly, 2015a).

<u>CMADC and the 'Educational Turn'</u>

In recent years an 'Educational Turn' (as discussed in chapter one) has been identified in artistic and curatorial practises (Aguirre et al, 2010) and has brought a reconsideration of the role of the studio in exploring education as medium for artists. Through this lens, learning at CMADC is focused on the artistic exploration of questions rather than on direct teaching or the production of any art object. Identifying with Holert's view in his chapter 'Latent Essentialisms: An E-mail Exchange on Art, Research and Education[11]' (Holert, 2010) CMADC aims to widen the boundaries of the teacher/student relationships towards non-linear learning dynamics, allowing ideas to unfold through artistic process rather than through the transfer of knowledge as an 'object'.

10 As evidenced in feedback from previous workshops (see Appendix D)

11 Like Holert, I prefer the term education over 'pedagogic' or 'andragogic' as the educational approach adopted in CMADC does not privilege the theme of teaching over learning and etymologically it is not posited upon the adult/child distinction.

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Figure 1 (a,b,c,d and e)
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, space layout for workshop events. Photograph.

As people share and explore ideas together during the CMADC workshops, a way of thinking and doing morphology is constructed through social interaction. The group provides a support for practice, and holds the focus of individuals as we sustain concentration through a series of questions, practices and moments of open discussion. The emphasis is not on skill or producing any art object but on creating an open and curious engagement with the ideas that are presented. I encourage participants to suspend judgment about their drawings and to focus on refining their understanding of the subject by 'thinking through drawing'. The workshops are a way to invite other people to participate in my artistic practice and feedback suggests that it is this 'entering' into my practice that excites and motivates people.

> I found the nature of the art/science collaboration inspiring, and felt free to ask questions that helped develop my own study (Artist).

To build on this, I make a point of talking to each person to support their understanding and to gain insight into their perspective. Different people have different questions and different priorities. For example, a dialogue with an engineer during the 'Drawing in the Fourth Spatial Dimension' workshop enriched my own understanding of how this idea could relate to structural engineering. In this way, my own practice evolves as a result of these workshops and the fresh insights they provide.

Through CMADC, I have cultivated a 'friendly' space where artistic research can be shared in a way that relates to concerns recently presented at the Society for Artistic Research event[12] 'Unconditional Love' (The Society for Artistic Research, 05/07/15), in which Emma Cocker and Joanne Lee curated the exposition of research 'Care + Attend' (Cocker and Lee, 2015). This composite of fragments and extracts[13] explored the principles of care and attention, seeking to develop a research vocabulary based on 'receptivity, openness, fidelity, integrity, intimacy, friendship and commitment' (ibid). CMADC aims to share in this vocabulary while also relating to Kristina Lee Podesva's short online article 'A Pedagogical Turn: Brief Notes on Education as Art' (2007), in particular to the following characteristics:

> […] a dependence on collaborative production, a tendency toward process (versus object) based production, an aleatory or open nature and a preference

12 The Society for Artistic Research (SAR) Spring Event, 30th April-1st May 2015, Chelsea College of Arts, London.

13 Cocker and Lee invited a range of artists & writers to share and reflect on their own processes. Contributors included Kate Briggs, Daniela Cascella, Belén Cerezo, Emma Cocker, Steve Dutton and Neil Webb, Victoria Gray, Rob Flint, Mark Leahy, Joanne Lee, Martin Lewis, Sarat Maharaj, Brigid McLeer, Hester Reeve and Lisa Watt.

for exploratory, experimental, and multi-disciplinary approaches to knowledge production (Podesva, 2007).

While relating to the 'pedagogical or educational turn' (Aguirre, O'Neil and Wilson, 2010) CMADC can be understood in the context of artistic experiments in learning. Through workshops, CMADC creates a temporary structure that offers potential for a transformative learning and social experience and as such relates to Beuys's concept of Social Sculpture[14]. As a space that offers insight into artistic process while also making available a small object collection: specimens, artworks, microscopes, books, educational aids (handouts and wooden shapes), CMADC relates to the 'opening up' of artistic practice as, for example, in Tracey Emin's 'Museum[15]'(Medina, 2014). With links not limited to the context of art, CMADC also relates to Bruno Strasser's science education project 'Bioscope' at the University of Geneva (Bioscope, 05/07/15) that creates an innovative and tactile environment for experimental and non-hierarchical approaches to learning. There is also a link to Wertheim sisters interdisciplinary project the 'Institute for figuring'. There are clear overlaps between the aims of CMADC and that of the IFF, which states the mission 'to contribute to the public understanding of scientific and mathematical themes through innovative programming that includes exhibitions, lectures, workshops, and participatory, community based projects.' (Wertheim, 2003). In support of the workshops at CMADC, the *Isomorphology* book (Anderson, 2015a), inspired by Paul Klee's *Pedagogical Sketchbook* (Klee,1977) provides a theoretical and practical framework that acts as a general guide for workshop activities.

This model (CMADC) has evolved from my own artistic practice that involves dialogue and co-production with practitioners in other disciplines, and which has focused on process rather than end product. Whilst consistent with the work of others, CMADC also builds its own approach by a distinctive combination of the following characteristics:

1. Question Asking

Question asking is promoted as a way of structuring the workshops. In the workshop context, initial questions are offered to provide a 'ground' for the questions of others. To foster an environment where participants feel comfortable to ask *any* question,

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14 A concept and medium the artist devised and later theorised in "I am Searching for Field Character" (Beuys, 1973) which articulates his belief in the creative capacity of every individual to shape society through participation in cultural, political, and economic life

15 Emin took a five-year lease on a retail space near London's Waterloo Station (1996-2001) and turned it into a combination artist's studio, gallery and shop.

emphasis is placed on the process-based nature of learning and we make explicit that the collaborative workshops have themselves emerged out of question asking.

This combination of question asking and drawing engages the participants in an active way, avoiding a passive transference of knowledge and any conception that knowledge is an 'object' that can be passed on. Through this approach new questions are generated, which feed the workshop and the ongoing collaborative process[16].

2. Collaboratively led

Drawing has been the basis of the collaborations of this research. Each workshop is co-led by myself and a scientist and offers a unique drawing method that participants can use to engage with the subject of the workshop. Through the workshops the scientist and I share our methods of observation and enquiry with the group. Opening and sharing have been key aspects of how the collaborations work out in the 'live' and collective context of the workshops. The collaboration is extended and enriched through receiving the diverse responses of the individual participants, which generate new perspectives on the questions we offer. For the group, participating in art/science collaboration provides an opportunity to challenge ideas about the boundaries between art and science.

3. Role of drawing as process and object in the workshops

The epistemological value of drawing is presented as both process and object. Learning during the workshop is process-oriented but uses drawing objects including my own drawings, etchings and artist's book *Isomorphology* (Anderson, 2015a) alongside handouts and fieldwork guides as educational tools during the workshops. Participants are encouraged to find their own individual way of coming to terms with the subject through drawing methods that can be developed independently after the workshop. The value of the drawing process for understanding complex scientific matters and creating morphological knowledge is often part of the discussion and feedback at the end of each workshop.

4. The Space

I have curated the CMADC space to create an environment conducive for artistic and intellectual exercise. I have brought elements of the scientific lab space I have worked

16 For example, the question 'how to draw with 4D perspective?' came from a participant at the 'Drawing in the fourth spatial dimension' workshop. Alessio and I will develop this question in dialogue with the participant.

Figure 2.
KILBURN, John, 2015. Poster for CMADC launch event.

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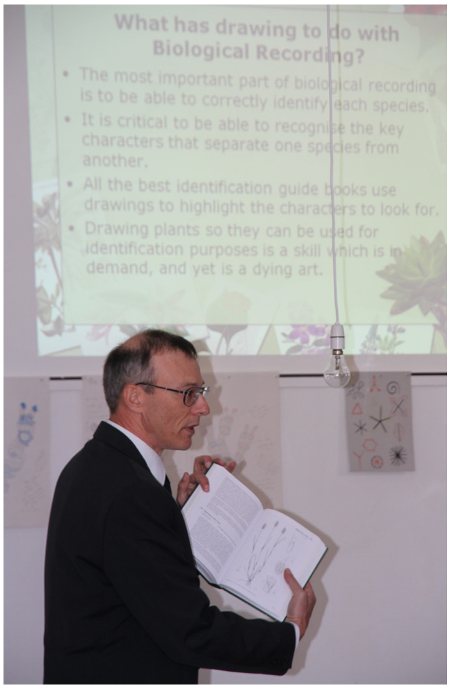
What has drawing to do with
Biological Recording?
The most important part of biological recording is to be able to correctly identify each species.
It is critical to be able to recognise the key characters that separate one species from another.
All the best identification guide books use drawings to highlight the characters to look for.
Drawing plants so they can be used for identification purposes is a skill which is in demand, and yet is a dying art.

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Figure 3.a.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event. Photograph.
Figure 3.b.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event. Photograph.
Figure 3.c.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event, Colin French presenting. Photograph.
Figure 3.d.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event, Courtenay Smale presenting. Photograph.
Figure 3.e.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event, Gemma Anderson presenting. Photograph.
Figure 3.f.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, launch event, table set up with publications and educational models. Photograph.

in at the NHM: Specimens, petrological and biological microscopes, and a minimal aesthetic; together with elements of the 'studio': Artworks, drawing materials and books. The aesthetics of this environment is intended to help the mind sustain focus as it wanders away from the subject, as each object and image has been carefully selected to promote concentration on drawing and morphology.

CMADC is one large room with tables and chairs, drawing boards, drawing materials, a magnetic strip for hanging images from the walls, a wall with the forms and symmetries of Isomorphology displayed through wooden models and shelves full of educational objects. The space is set up to be dynamic and to change in response to the diverse nature of the workshops.

5. Educational Object Collection

This project repurposes redundant scientific equipment[17] donated by the University of Exeter and Camborne School of Mines for new questions and discoveries. The CMADC collection of educational objects includes historic wooden crystal structure models, microscopes, glass crystal system models, taxidermy, mineral and animal specimens[18]. My own artworks are selected and displayed amongst other supportive imagery to aid understanding in each of the different workshops and a collection of books relating to each workshop is available. The combination of artistic and scientific learning resources makes this space distinctive from a conventional scientific lab or artist's studio.

Workshop Programme

CMADC began with a launch event[19] (Fig.2 and 3) consisting of three presentations; I introduced my artistic research and it's evolution to the point of CMADC; mineralogist Courtenay Smale spoke of the value of the close observation and handling that drawing facilitates as a way to understand the more subtle differences between mineral specimens[20] and Dr Colin French from the Cornwall Botanical Group (CBG) discussed how the most effective plant identification guides still use drawings to illustrate the

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17 10 x M15c Vickers Light Microscopes and biological slide collection for observation and drawing, 8 x Monocular Carl Zeiss petrological microscopes and slide collection for observation and drawing

18 Specimens are a combination of my own collection and some on loan from the University of Exeter teaching collections.

19 Hernly described this event in a review published on the Campaign for Drawing website in April 2015: 'What shone through each of these presentations was the complete mutual respect all three speakers have for one another's work' (Hernly, 2015).

20 Smale supported this point by a discussion of his own experience of the importance of drawing crystal models when he was a student at Camborne School of Mines in the 1970s, (drawing has since fallen out of practice at CSM).

descriptive text[21]. French supported this preference by saying 'This is very difficult to do with photographs and I have yet to see a wild flower guide that has successfully used photographs for this purpose' (French, 2015, personal communication). French then explained the 'ERICA' (French, 2010) database he has developed for recording plant species found in the British Isles and emphasised the value of drawn rather than photographic records. He concluded by connecting with the Isomorphology project, arguing for its potential to become integrated into current data collection practices in the field[22].

<u>Drawing workshops</u>

The maximum capacity for each workshop was set at fourteen participants. Fees were set to be affordable at £15 full rate and £10 concession[23], to offer the workshops to a wide audience[24]. All workshops ran from eleven am until four pm.

<u>Isomorphology of the Lizard workshop, 29th of March</u>

This workshop in collaboration with botanical scientist Colin French explored field- and studio-based drawing practices to enquire into plant morphology(Fig.4). The Isomorphology study provided the framework for the identification of a diverse range of plant specimens in the Loe Bar area (an internationally renowned botanical site).

In the morning, we combined the practices of observation, walking and drawing to discover the shared forms and symmetries of plant specimens at a macro-scale in the Loe Bar area. French used his botanical knowledge and recording database 'ERICA' to identify different plant species in situ and offer insight into their characteristics and behavior, while I corresponded the plant morphology with the forms and symmetries of Isomorphology. Participants then began their own independent search for specimens and started to draw in the field. The approaches of drawing, observation and walking allowed for intuition, imagination and improvisation while the scientific practice of identification (which names and quantifies) allowed for analysis.

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21 Because drawings enable the plant to be laid out in a way which highlights the salient characteristics which separate one species from another.

22 French has since integrated the Isomorphology forms and symmetries into his ERICA data collection software (see appendix A.8)

23 Workshops were supported by the Cornubian Art and Science Trust and The Arts Council England.

24 The workshops have been promoted through Mail Chimp email newsletters (through my own network and through the CAST network), posters and via twitter (Isomorphology and Campaign For Drawing, and through twitter). Each workshop has been fully booked with a waiting list and a variable number of people who could not make it on the day (Iso-2, Maths-3).

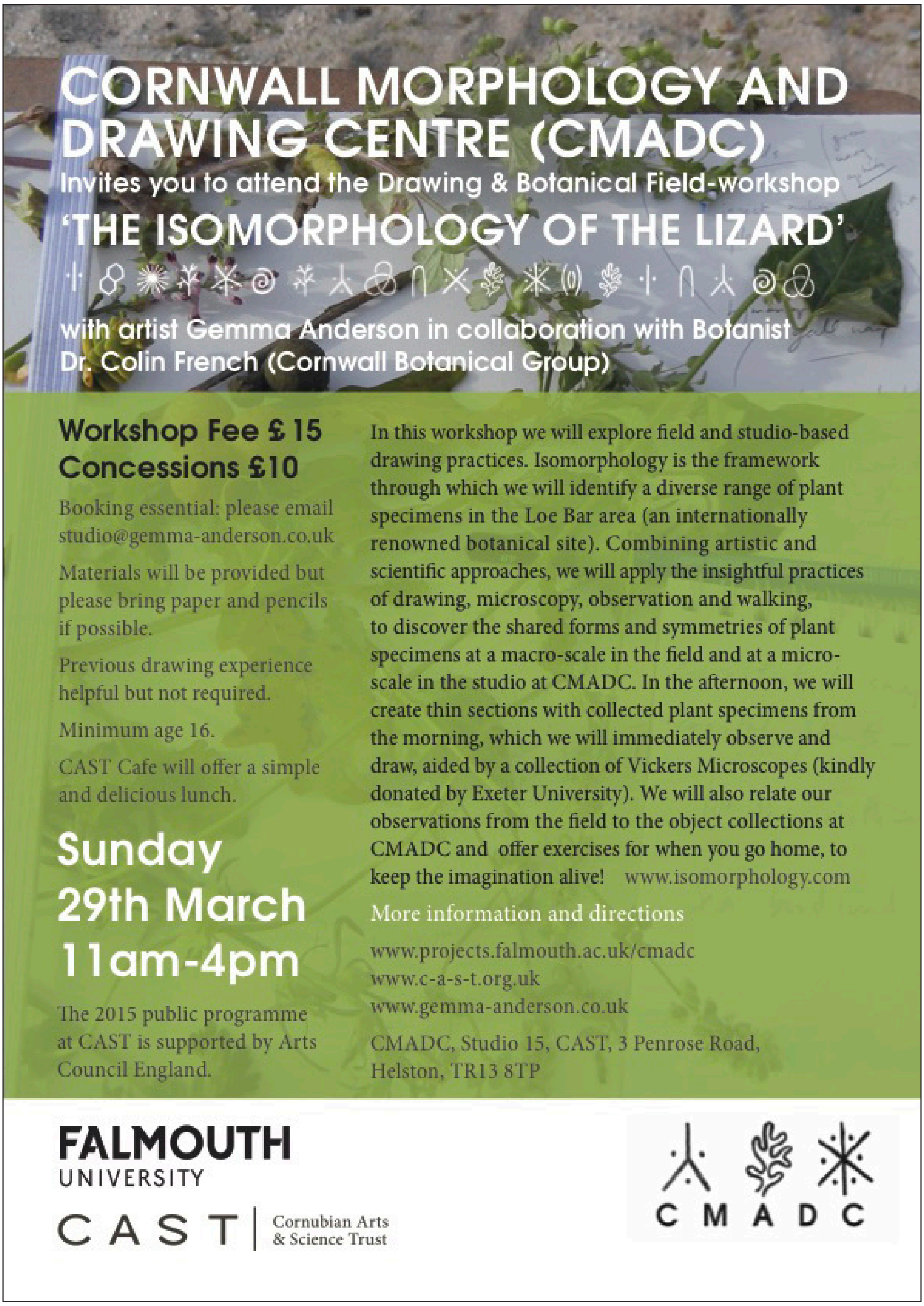

Figure 4.
KILBURN, John, 2015. Poster for 'The Isomorphology of the Lizard' workshop.

In the afternoon, participants created thin sections from the plant specimens we collected in the morning, which were then observed and drawn at a micro-scale in the CMADC studio using microscopes. I then guided participants through the Goethe inspired drawing method while French spent time helping each participant to identify and interpret the specimen they had selected for drawing. We then related our observations from the field specimens to the mineral and zoological specimens at CMADC based on the forms and symmetries of Isomorphology.

During this workshop (Fig.5) I displayed a series of related artworks, including original Isomorphology etchings (see chapter four) a facsimile of Goethe's drawings of plant morphology and my own Goethe inspired 'urpflanze' etching (see page 145). The objects that were set up to support this workshop included ten zoological microscopes and a botanical slide collection[25].

After the workshop, I asked French to reflect on the impact of the workshop on his own work, he offered the following reflections:

> The terminology associated with plant taxonomy is horrendous, and very off-putting for students starting to learn plant identification. Anything that can be done to simplify this learning process – a more visual approach similar to what we have done today – must be a good thing, as it would demystify plant taxonomy, and would encourage more people to be involved.

French could see potential for incorporating the forms and symmetries of Isomorphology as a complementary 'system' for classifying flowers within the ERICA software and has since successfully incorporated Isomorphology as a functional component in his ERICA system. He described one advantage of this approach to be the liberation from the dependency on 'correct' identification of the flower parts, which is difficult for many plant families. He says, 'deciding whether a flower has six fold symmetry is much simpler than determining whether it has 6 petals, or 3 petals and 3 sepals, or has 6 tepals, and as a result will enable the layman to more effectively use the software'[26](Fig.7 and Appendix D.8.). More broadly, French's promotion of symmetry as an identification and organising principle, supports the kind of classificatory pluralism Isomorphology has adopted from Dupre, as discussed in chapter four.

25 A slide preparation kit was provided by George Littlejohn, Plant Scientist, Exeter University
26 ERICA Database was used in the 'Isomorphology of the Lizard' workshop

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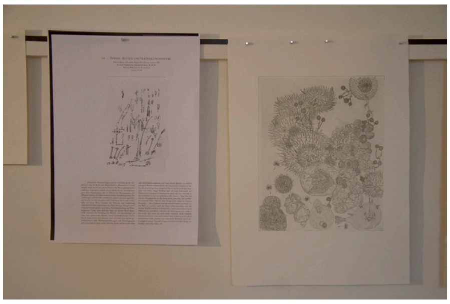

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Figure 5.j.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants looking at a collected fern species with Colin French and Gemma Anderson in Loe Bar Nature Reserve. Photograph.
Figure 5.k.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants drawing with specimens and microscopes. Photograph.

Figure 5.a.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants drawing with specimens and microscopes. Photograph.
Figure 5.b.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants, Gemma Anderson and Colin French at Loe Bar beach. Photograph.
Figure 5.c. TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participant drawing collected field specimens, at Loe Bar nature reserve. Photograph.
Figure 5.d.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, drawing (Goethe) and etching (Anderson) used as educational resources during workshop. Photograph.
Figure 5.e.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, specimens collected from the field. Photograph.
Figure 5.f.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants discuss specimens with Gemma Anderson. Photograph.
Figure 5.g.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, botanical microscope set up for drawing. Photograph.
Figure 5.h.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, participants drawing with specimens and microscopes. Photograph.
Figure 5.i.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop, Colin French and Gemma Anderson in Loe Bar Nature Reserve with participants. Photograph.

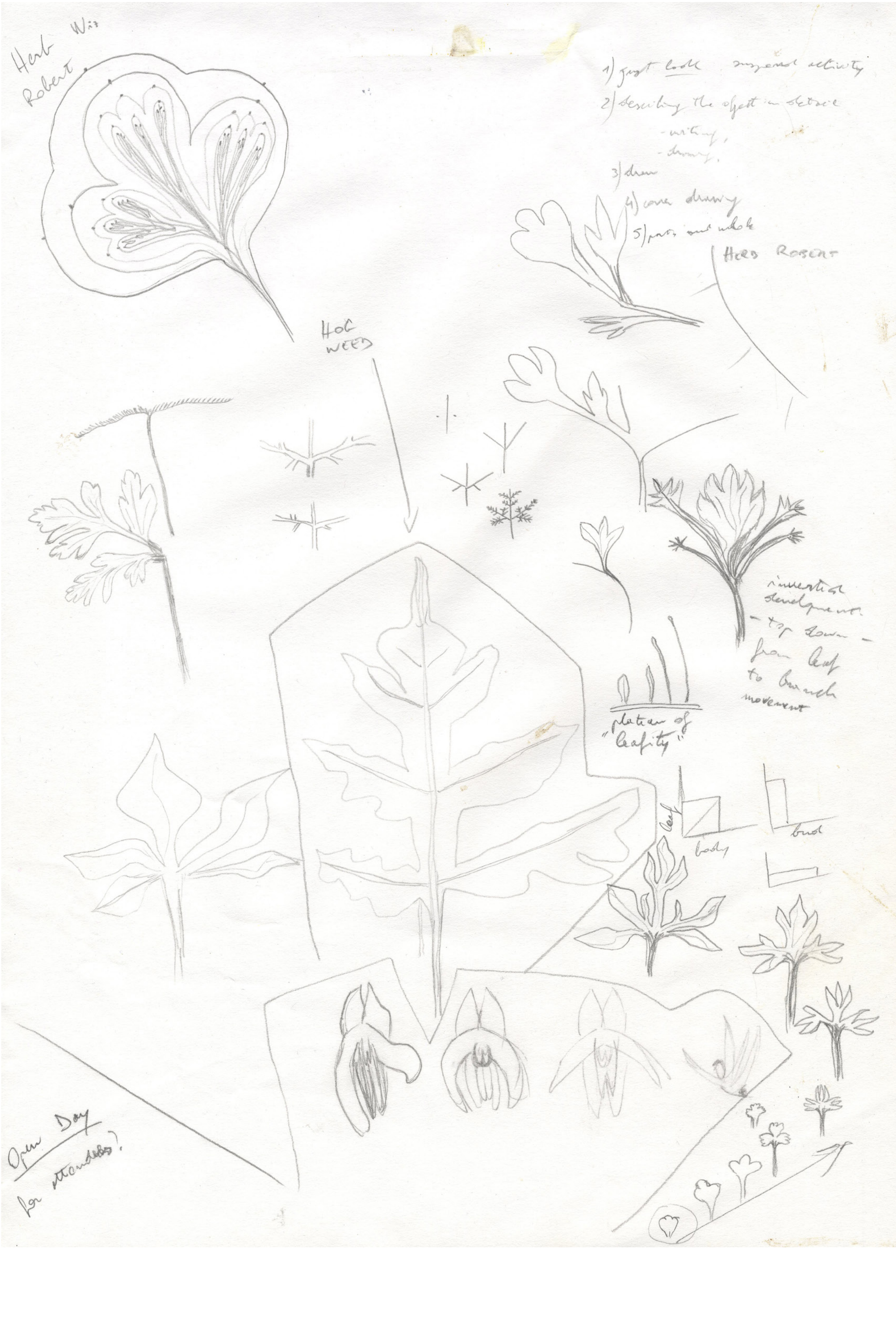


Figure 6.a.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop: Goethe drawing method. Pencil on paper.

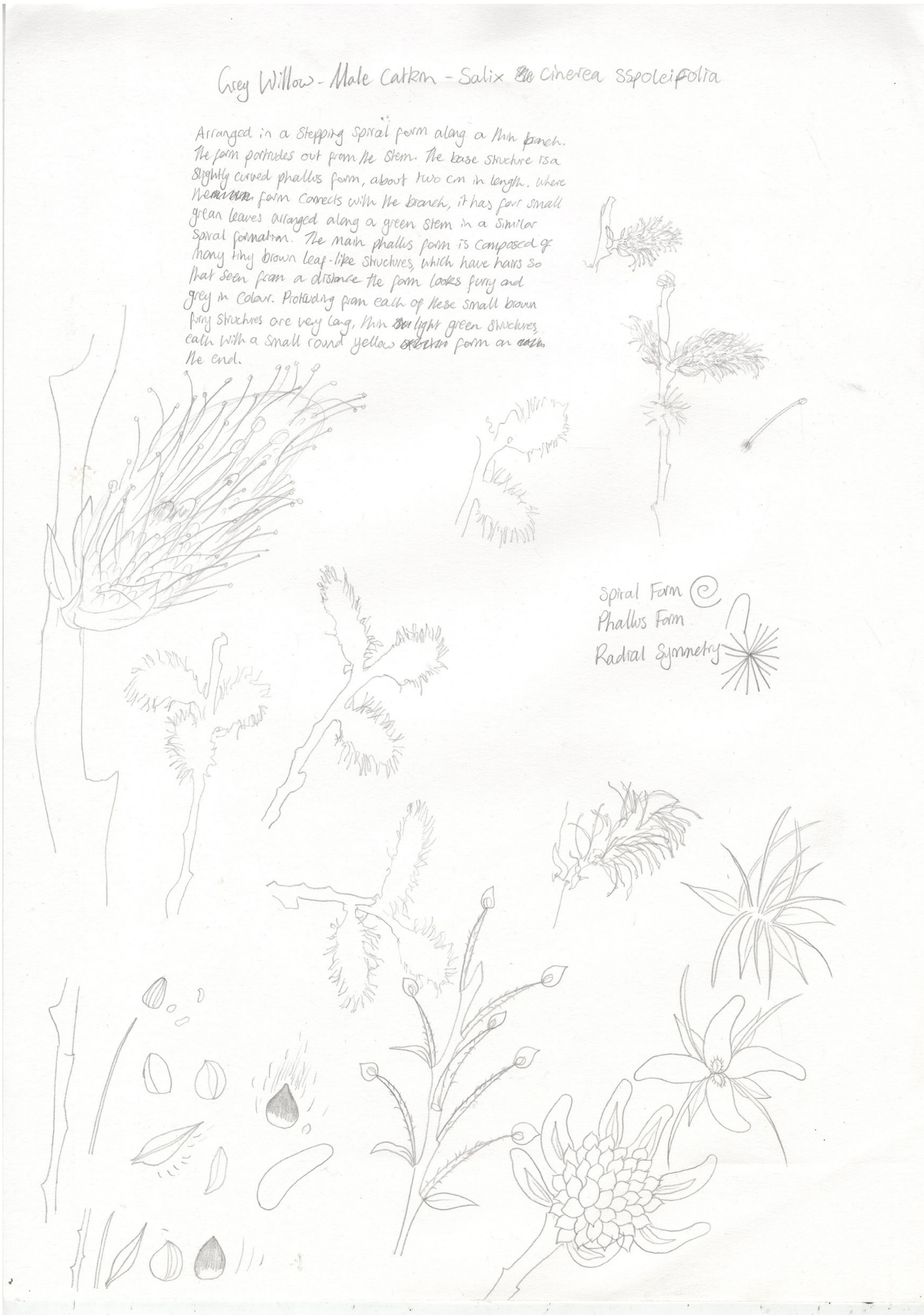


Figure 6.b.
GAWLER-WRIGHT, Minna, 2015. Cornwall Morphology and Drawing Centre, Isomorphology of the Lizard workshop: Goethe drawing method. Pencil on paper.

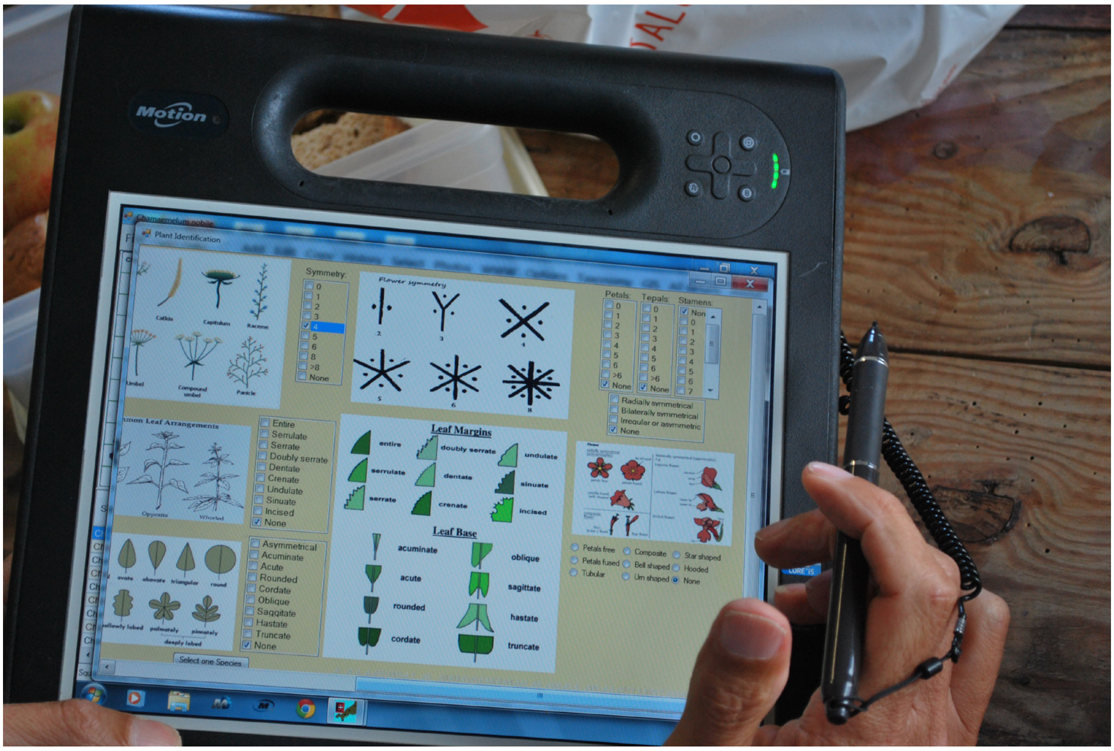


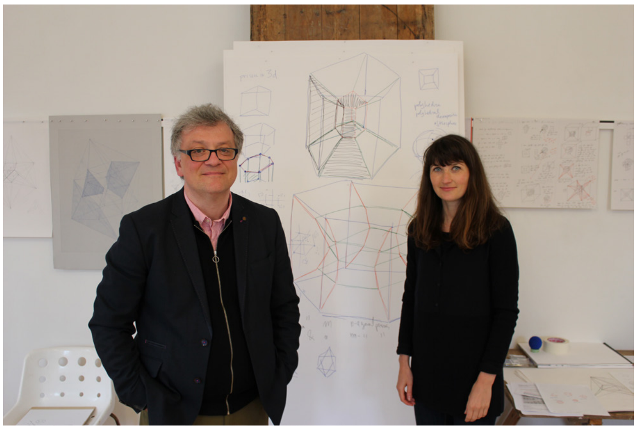
Figure 7.
TEMPINI, Niccolo, 2015. ERICA Computer software with Isomorphology integrated into identification search. Photograph.

Outcomes for participants

An important aim of the workshops is that they feed the creative practice of participants(Fig.6). I structured the feedback questions in a flexible format to ensure that participants would feel at ease explaining how the workshop practice developed their morphological insight. After the workshop, I received further feedback from a participant[27] who contributed artworks to the 'Cultshare' exhibition (Cultshare, 05/07/15) in Penryn Arts Festival, which had been inspired by the Cornwall Morphology and Drawing Centre.

27 Further feedback on how the workshops impacted a photographers artistic practice can be found in appendix D.4.

Figure 8.
KILBURN, John, 2015. Poster for 'Drawing in the Fourth Spatial Dimension' workshop.



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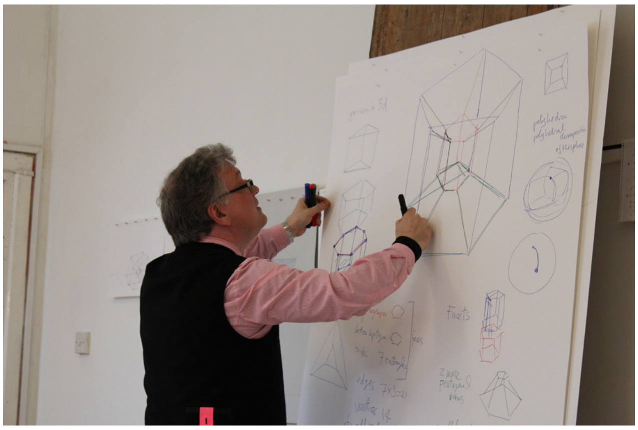

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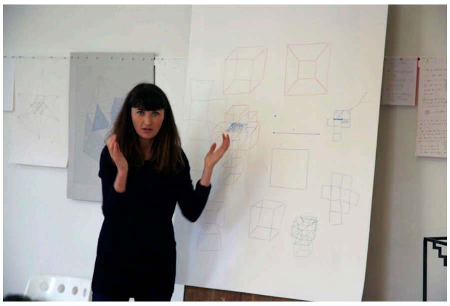

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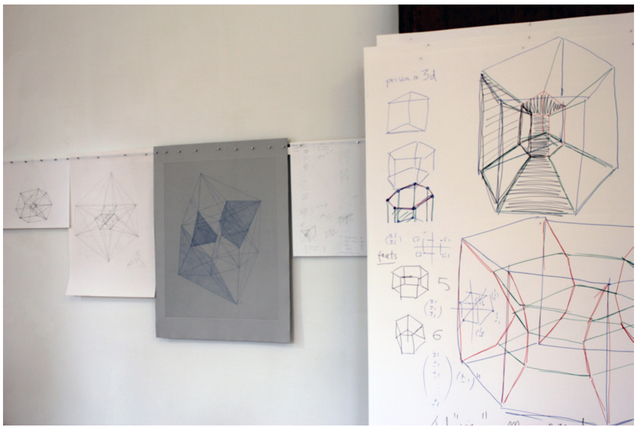

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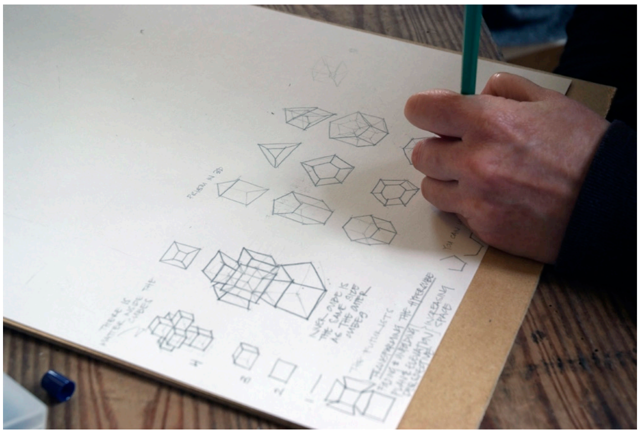

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Figure 9.a.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti and Gemma Anderson. Photograph.
Figure 9.b.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti drawing a four dimensional prism. Photograph.
Figure 9.c.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Terry Pope with Participants. Photograph.
Figure 9.d.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti sharing ideas with participant. Photograph.
Figure 9.e.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti uses a model of the hypercube to illuminate the concept of the fourth spatial dimension. Photograph.
Figure 9.f.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti and Gemma Anderson. Photograph.
Figure 9.g.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Alessio Corti drawing the fourth spatial dimension. Photograph.
Figure 9.h.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Artworks used as educational resource during workshop. Photograph.
Figure 9.i.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Participant drawing during workshop. Photograph.

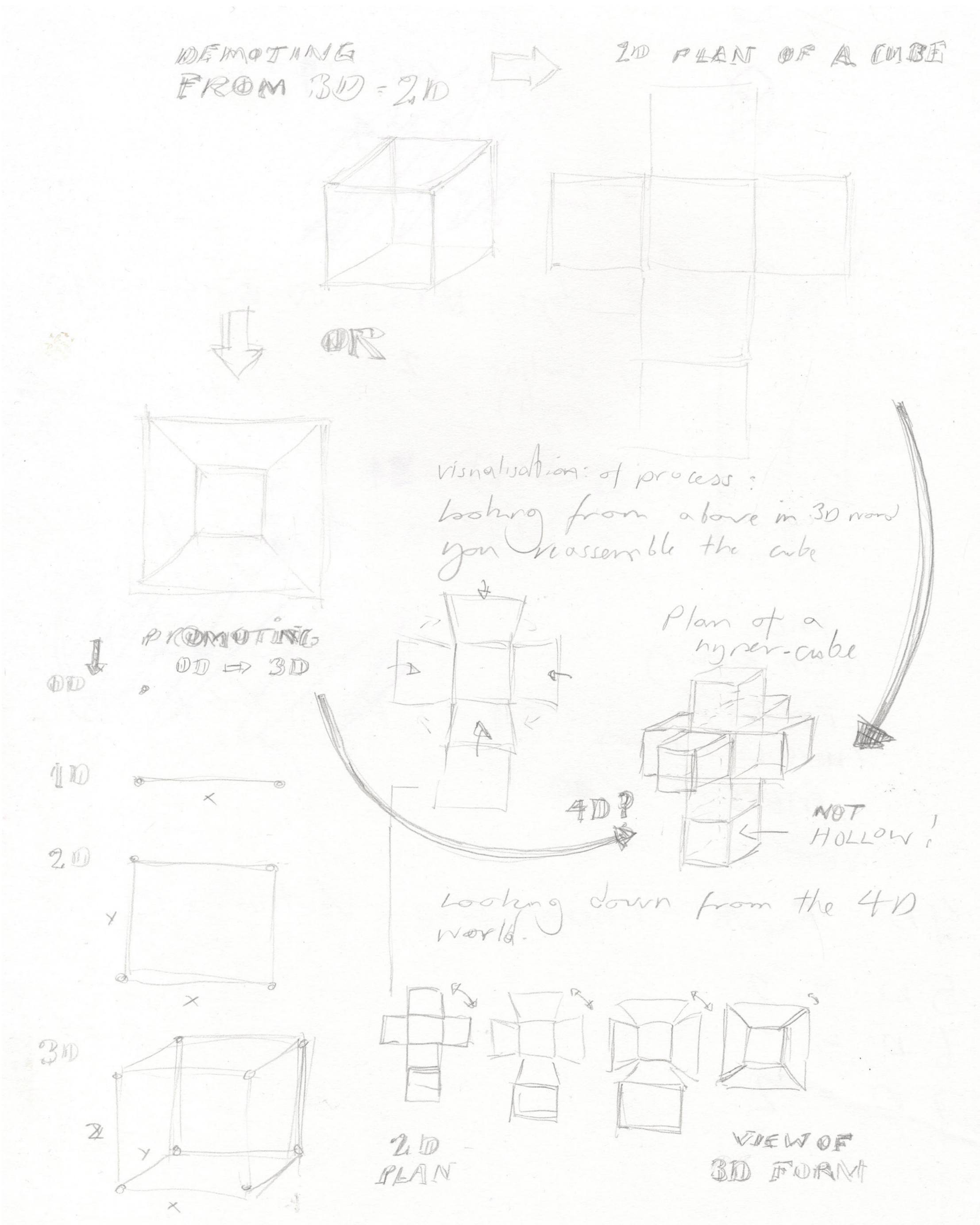

Figure 10.a.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Participant drawing.

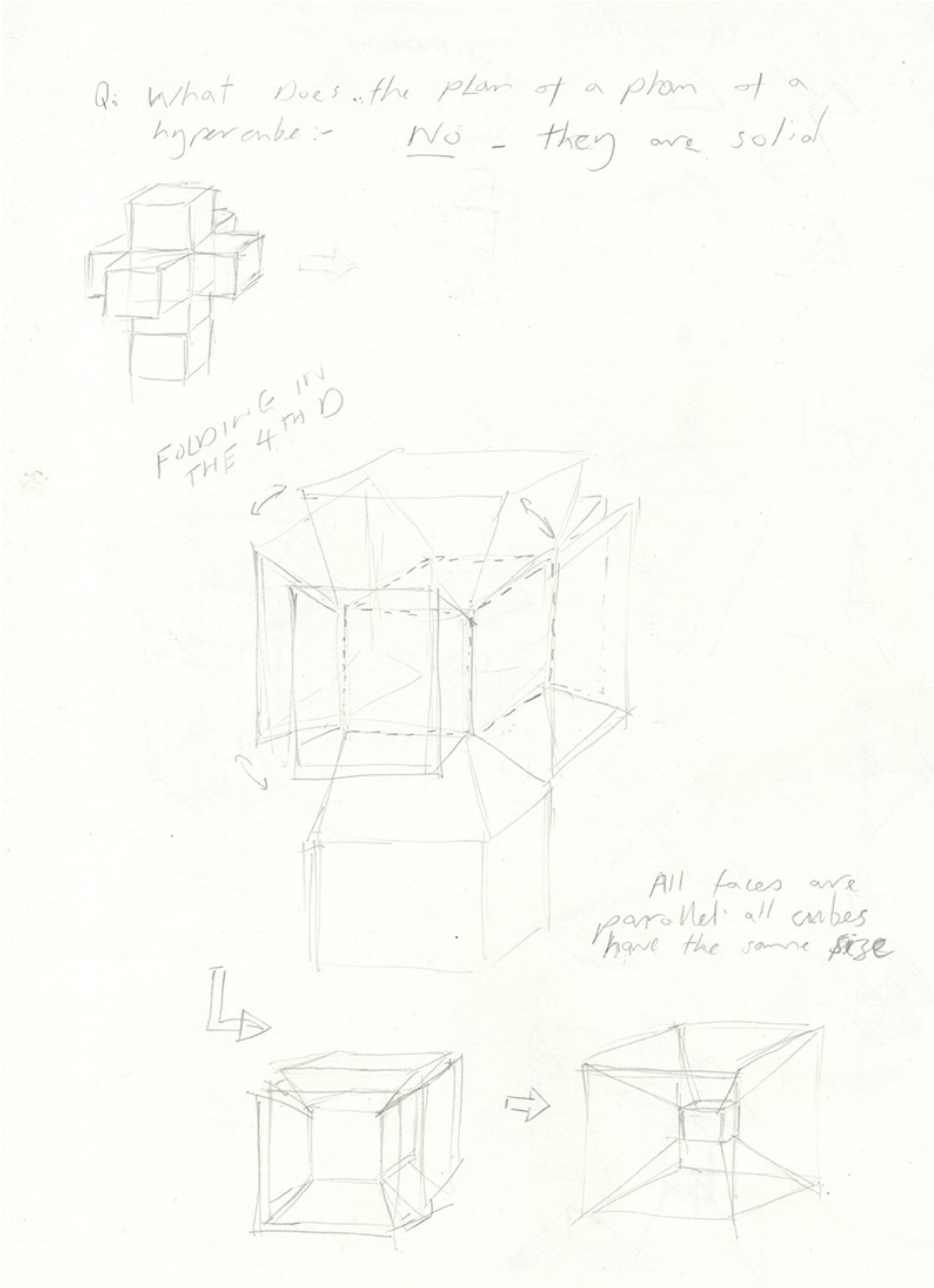

Figure 10.b.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing in the Fourth Spatial Dimension workshop, Participant drawing.

Drawing in the Fourth Spatial Dimension workshop, 25th April

Since developing the concept of 'Drawing in the Fourth Spatial Dimension' (Anderson and Corti, 2015) in collaboration with Professor Alessio Corti (Imperial College, Mathematics Department), we wanted to see if our approach could be shared through the form of a public workshop (Fig .8 and 9). We developed a workshop based on the following questions:

- What is the fourth dimensional space?
- How can the fourth dimensional space exist when reality is three-dimensional?
- Can 4D space be represented in a three-dimensional reality…And in a two-dimensional reality…Can it be drawn?

With these questions as a starting point Corti and I guided participants through drawing in the fourth dimensional space by analogy and intuition. We integrated the key concept of 'dimensional promotion' that had been useful in our research through images from our own collaborative research work.

The goal of this workshop was:

(a) visualization and drawing of objects in 4 dimensions. The point is not to make art objects but to make drawings that create images in the mind.

(b) consistent effort to encourage participants to share thoughts and ask questions.

Through this approach we invited the participants[28] to take part in our collaboration and to potentially change its direction.

The workshop

The morning began with my introduction to the concept of the fourth spatial dimension through drawing the hypercube. Corti joined in drawing at the point when we began to fold the drawn 3D plan up into a 4D cube (see Appendix D.1). All participants managed to successfully draw the folded-up 'hypercube' before lunch.

After lunch, prompted by the question[29] 'Is it possible to draw a prism in 4D?', Corti introduced drawing prisms in 4D using prisms in 3D as facets. The advantage of working with 3D prisms is the infinite variety of 3D shapes (polyhedrals) that can be drawn.

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28 Participants included academics, students, amateur and professional artists, illustrators, architects & basket makers, yoga therapists, art curators and naval engineers.

29 The question 'Is it possible to draw a prism in 4D?' was posed by a participant in the morning.

Time was given for participants to attempt their own drawings before Corti draws in front of the group.

The workshop ended with a discussion about why Corti draws in 4D in his own work with 4D reflexive lattice polytopes from the Kreuzer-Skarke (Kreuzer 1992) classification and how this collaboration led to developing a new method to draw a tree in 4D, which led to a shift in my own art away from the naturalistic, as discussed in chapter seven. Corti also spoke of how most mathematicians only use computer-models to visualise equations. He has used drawing since he was a teenager and teaches these techniques to his first-year students. He emphasised that this is an area he would certainly like to develop as he thinks that the act of drawing encourages close observation in a way that is difficult with computer-modelling, saying 'drawing provides a level of interpretation that is distinctly human and encourages understanding' (Corti, 2015, personal communication).

The Space

During the workshop, a selection of artworks and objects were installed in the space to support the concepts explored in the workshop. I installed a large drawing board so that Corti and I could draw 'live' in front of the group throughout the workshop.

Reflections

Encouraging participants to share their questions enabled a personal and sincere engagement with the task. One participant asked a question about how to draw a prism in the fourth spatial dimension and this changed the direction of the workshop because drawing a prism requires different visualisation techniques to those of the cube. In this workshop it was very exciting to see participants attempt their own drawings of 4D prisms before being shown, as this evidenced drawings epistemological role in their understanding. Looking at participants' drawings (Fig.10), we could see that all understood the main point: to build faith in the concept of a fourth dimension and to achieve some way of it being accessible through drawing.

Some participants described finding a new way into mathematics through visualization and drawing while others gained insight into the role of the imagination in science. The following quotes reflect themes from participant feedback:

> I thought the maths would be challenging but actually it was surprisingly clear (Engineer).

> I liked the fact that we were visualizing algebra- it makes maths suddenly tangible for me. I turn off when I see numbers. This workshop made maths interesting and relevant to how I learn best, drawing can be related to anything (Falmouth School of Art graduate).
>
> The workshop helped me to understand the concept of the fourth spatial dimension by thinking through drawing, knowing in action (Design Professor).
>
> I found drawing helped to understand what the forms were. It would be hard to follow if we weren't drawing at the same time (Basket maker).

Outcomes

Corti and I have collaborated since 2010 but this was the first time we had collaborated through the medium of the public workshop, which allowed us to improvise in a new way. On reflection, Corti and I realised that to think of this workshop as a way to show 'impact' is not integral enough. At a minimum, this is not 'traditional' science communication, but an honest effort to find new ways to share research and understanding. As such, our approach has been recognized as innovative by the Science Museum 'Mathematics Festival' (2015) and the 'Thinking Through Drawing' symposium 'We All Draw' (2015) who have both invited us to develop this workshop as part of their programme. These invitations reinforce our belief that it is important to be open about outcomes, as the impact goes further than the workshop[30], and it is quite possible that further outcomes will become apparent later.

The workshop had the following impact on our collaboration

(a) Corti has planned to begin serious work on the 473M+ reflexive lattice 4-topes. The workshop made him more urgently aware that his team needs to develop software for computer visualization of lattice 4-topes as a tool for mathematical research. The development cycle will start from developing conventions for foreshortening objects in 4D perspective and experiment with physical drawings with pencil on paper by Anderson.

30 For example, after the workshop, I received further feedback from a second participant, this time an Illustrator who contributed 'The wildlife photographer of the year as filtered through the hypercube' artwork and zine (see appendix D.4) to the 'Cultshare' exhibition (Cultshare, 05/07/15) in Penryn Arts Festival, as inspired by this workshop.

(b) In our discussion when reflecting on the workshop, Corti discussed his original approach to the undergraduate teaching of algebraic topology by systematic drawing: many drawings on the board with coloured pens, encouraging students to develop their drawing skills by making their own drawings as a way to put the algebraic topology into 'the part of the mind where words can't go'. This led to imagining what kind of drawing software might support this teaching methodology

Drawing is the link between Corti's research and my own. Through this workshop, we both experimented in doing something mutually new through our collaboration. For Corti this was the first time to interact with the public in a workshop format. Both the workshop itself and Corti's teaching of algebraic topology are instances of the role of drawing in creative teaching.
Our approach supports the argument for drawing as a way of knowing - especially drawing effected in collaboration with scientific practices and instrumentation - representationally, analytically, and in terms of interpretation, which can achieve a new understanding of for both artists and scientists.

<u>Drawing the Six Crystal Systems workshop, 25th July</u>

This workshop emerged out of a collaboration with mineralogist Courtenay Smale that began in 2011 when I was working from the Rashleigh Mineral Collection (see chapter four). In this workshop we explored the role of crystal models as teaching aids[31] and enquired into what may have been lost with their dismissal in favour of computer modelling. We built our own experience of handling, rotating and drawing three-dimensional wooden crystal models to explore the six crystal systems (Cubic, Tetragonal, Orthorhombic, Monoclinic, Triclinic, Hexagonal), and to recognise examples of these basic forms in macro and micro minerals/specimens (Fig.11).

The Space

For this workshop, I had previously loaned a set of wooden models from Camborne School of Mines with intention of re-purposing the models as educational objects alongside corresponding mineral specimens. Smale and I laid out the wooden models and mineral specimens to show the six crystal systems alongside glass and molecular models that related to one of the six crystal systems. We accompanied these models with an educational handout on 'Crystal Systems' that participants could keep (See appendix D.2). The models were positioned near a display my own etchings of minerals

31 Which where used actively until the era of computer models

drawn based on their resemblance to plants, animals and landscapes which disrupted conventional ideas of scale, for example, drawing a mineral in place of a mountain.

The Workshop

In the workshop (Fig.12), we explored how drawing a wooden model of a complete crystal structure can help to draw the same structure in an incomplete mineral specimen. We also assessed the contribution of handling specimens to morphological understanding when drawing mineral form. We used drawing at all stages of the process to guide and enhance our own understanding.

The workshop began with a talk from Courtenay Smale about crystal systems, mineral growth and the history of the wooden crystal models[32]. This talk offered insight into the six crystal systems and their characteristics (planes of symmetry, rotation etc) and their role in mineral classification.

Based on my own work with zoological scientists and collections, I then offered a discussion based on comparing the crystal models (and their modifications[33]) and mineral specimens with zoological 'type' specimens and the specimens diagnosed as the same species. At this point I also relate back to the types of form and symmetry and possible modifications of Isomorphology.

To move towards the drawing activity, we then discuss the importance of handling and rotating models and specimens to create a 3-dimensional understanding rather than a 2d view of the mineral or model[34]. We then ask the group[35] to match the mineral specimens to the wooden models and to select a model and mineral specimen to draw.

---

32 By the late 1700s Schools of Mines in Germany and France (e.g. Freiberg and Paris) were supplied with models (mainly Pear or Maple, but also made in Metal, Glass, Plaster, Porcelain, Board, Paper, Wire) for the wider study of mineralogy and crystallography. Very often they were made on commission, their manufacture being a painstaking and expensive business. The earlier study of mineralogy and crystallography used contact goniometers to measure the angles between faces on individual crystals. In the 1800s these were largely superseded by optical goniometers which permitted a high degree of accuracy in measuring the angles.

33 We discuss the culture of 'theoretical crystallography' and the modifications which have been realized without observation in the field. These theoretical shapes follow the culture of 'doctoring' specimens (as was the case with unscrupulous mineral dealers) with the aim of enhancing their value. We follow this culture of 'doctoring' specimens, suggesting that we can use drawing as a way to create further modifications of the models.

34 Handling allows the observation of physical qualities and properties of minerals, which is very different to the contemporary approach which uses the two dimensional screen as the lens to view three-dimensional mineral visualizations.

35 16 participants including a botanical scientist, artist, two professional illustrators, FU BA Drawing senior lecturer, yoga teacher, conservationist, two GCSE pupils, a data analyst, a PhD researcher, an undergraduate Drawing and a Fine Art student, a researcher from Germany, and local artists (amateur and professional).

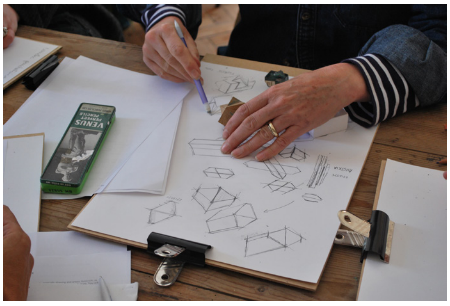
Figure 11.
KILBURN, John, 2015. Poster for 'Drawing the Six Crystal Systems' workshop.

a.

f.

b.

g.



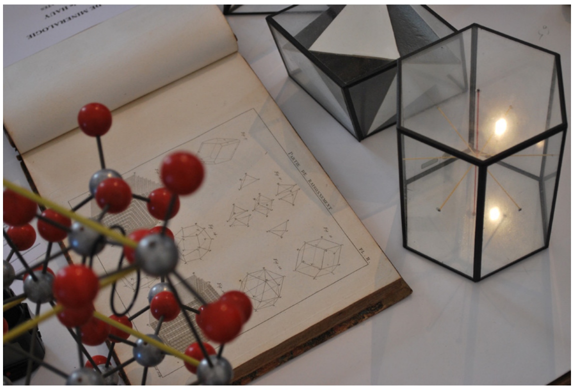
c.

d.

h.

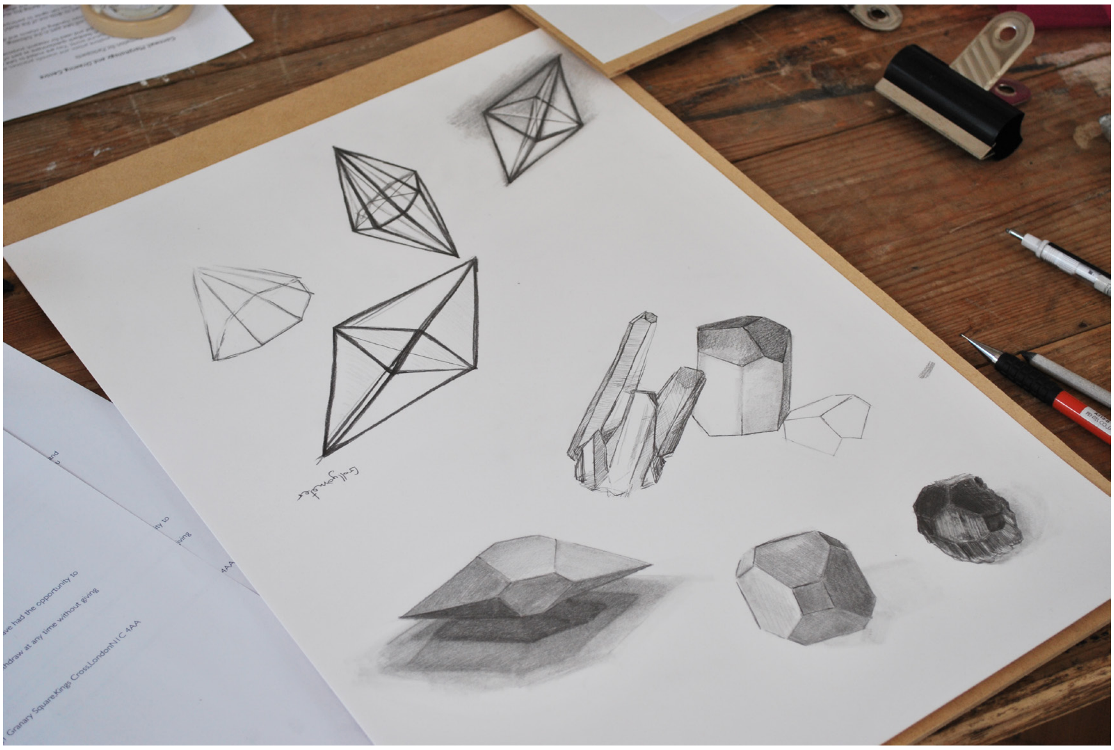
e.

i.

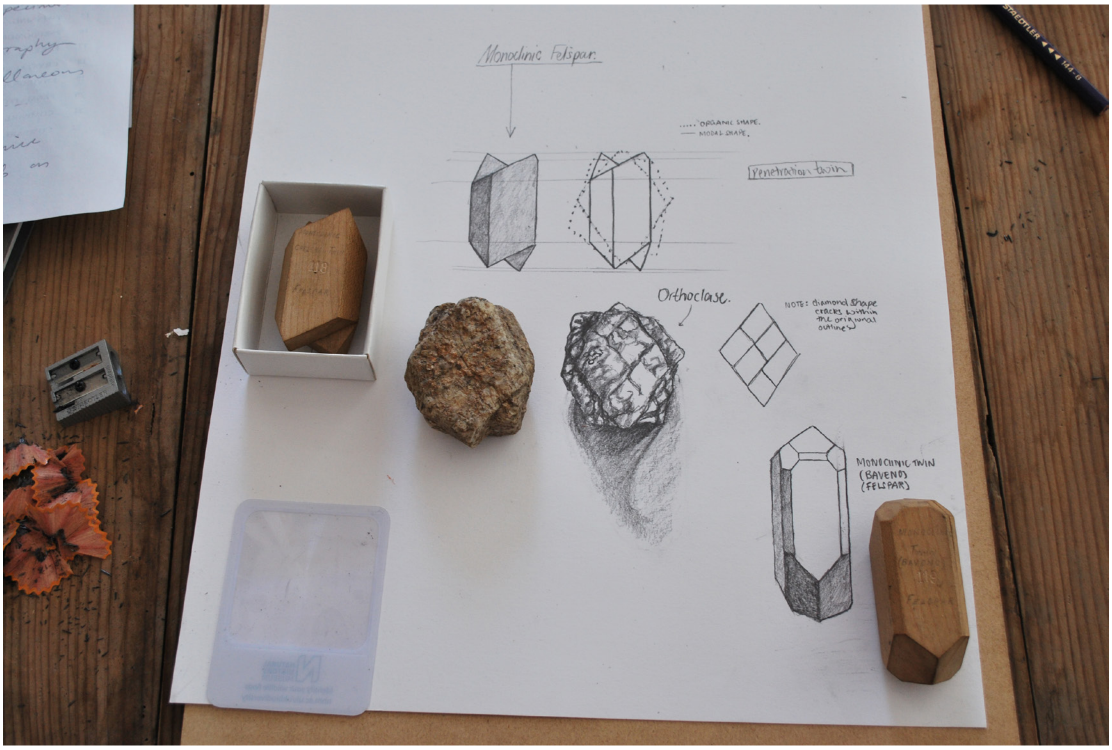

j.


k.

Figure 12.a.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Gemma Anderson presenting artworks of minerals. Photograph.
Figure 12.b.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Courtenay Smale and Gemma Anderson presenting workshop concept. Photograph.
Figure 12.c.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participant drawing wooden crystal models and corresponding mineral specimens. Photograph.
Figure 12.d.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Gemma Anderson and participant observing and discussing mineral specimens. Photograph.
Figure 12.e.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Courtenay Smale and participant observing mineral specimens. Photograph.
Figure 12.f.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop. Photograph.
Figure 12.g.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Courtenay Smale and participant observing and discussing mineral specimens. Photograph.
Figure 12.h.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participants drawing mineral specimens and wooden models. Photograph.
Figure 12.i.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Wooden crystal models and corresponding mineral specimens. Photograph.
Figure 12.j.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop. Photograph.
Figure 12.k.
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, Gemma Anderson and participants. Photograph.



a.


Monoclinic Felspar.
Penetration twin
Orthoclase.
MONOCLINIC TWIN (BAVENO) (FELSPAR)

b.

c.

d.

Figure 13.a.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participant drawing of mineral specimens and wooden models. Photograph.
Figure 13.b.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participant drawing of mineral specimens and wooden models. Photograph.
Figure 13.c.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participant drawing of mineral specimens and wooden models. Photograph.
Figure 13.d.
Participant, 2015. Cornwall Morphology and Drawing Centre, Drawing the Six Crystal Systems workshop, participant drawing of mineral specimens and wooden models. Photograph.

After lunch, I gave a talk about the mineral inspired artworks installed for this workshop. I discussed resemblance as the basis for these works, and suggested the observation and drawing of resemblances between mineral specimens as a guide for a more creative engagement with the mineral specimens. Referring back to the concept of 'theoretical crystallography', I encouraged participants to draw their own adaptation of the 'model' (Fig.13).

As a further suggestion I invited participants to follow the logic of minerals behaviour through drawing actions: joining, twinning, creating 'pseudomorphs', and 'doctoring' the specimen. I used my own 'Isomorphogenesis' work as an example of evolving form through a series of drawing actions to help participants follow a similar logic with the mineral specimens. During this drawing period, Smale and I walk around and spend time with individual questions and ideas.

Feedback[36] from the workshop demonstrates that handling the three dimensional models helped to draw and to understand the nature of crystal systems. When asked to describe how the handling and drawing of models and mineral specimens helped the understanding of mineral form, participants responded:
- that handling the specimen helped to understand the complexity of the crystal structure.
- handling and drawing the different models and specimens helped to understand the different structures through close observation and the 'formative' process of drawing.
- it was useful to rotate the model to see how the structure works. The models really helped to identify the different structures.

> This mode of scientific and creative observation allowed me to understand both the miniscule and giant scale at which these beautiful minerals form [...] the models did provide an educational basis for the perfect and theoretical form these crystals are based on (GCSE student).

The theme of scale: macro and micro, ran throughout the workshop and was supported by drawing minerals with petrological microscopes and mineral thin sections.
When asked about the value of working from the microscope and the specimen, one participant responded:

36 Further quotes from participants can be found in Appendix D.

> The microscope image took me straight to the macro viewed microscopic 2d image somehow suggested a larger landscape than the small pyrite crystal (Yoga teacher)

<u>The Art and Science of Systematics workshop, 3rd October 2015</u>

This drawing workshop was in collaboration with Natural History Museum (NHM) Entomologist Dr Gavin Broad and compared contemporary artistic and scientific approaches to taxonomy.

Broad explained the practice of taxonomy, particularly the act of describing species, in the curatorial setting of Natural History Museum (NHM). I presented my own field-based research on the role of drawing in contemporary morphology (Anderson, 2014a), the artistic project that unfolded during my residency at the NHM, and the Isomorphology system.

Participants were offered the opportunity to explore, through drawing, the differences between similar specimens from the Natural History collection that may represent separate species, and the description of species.

The Workshop

Broad's presentation covered his work as a taxonomist and curator of wasp collections at the NHM. He gave an overview of the various approaches to discovering, identifying and describing (wasp) species. Broad described how drawings are useful to identify the morphological features that distinguish one species from another, emphasising that drawing highlights relevant characters amidst complicated morphology and can provide an idealised visualisation of anatomy that is not necessarily apparent in a particular, unique specimen (Fig.14 and 15).

The Specimens

The specimens were pinned adult insects and microscope slides, all of the parasitoid wasp family Ichneumonidae[37]. The participants began to observe and draw specimens, paying attention to the identification of characteristic features. Several participants discussed questions of function with us during the observational drawing process.

37 The pinned insects comprised unidentified (mostly undescribed) species of the genus *Thyreodon*, about 30 mm long, two described but similar species of the genus *Enicospilus* (c.20 mm long); the microscope slides preserved wings of small (c. 5 mm long) ichneumonid wasps of the genus *Diadegma*.

Drawing helped participants to investigate both form and function and, for example, after drawing a specimen and asking Broad about the function, one participant said 'I found out that the hamuli[38] are design features for hooking up the wings whilst in flight'. There were also questions about the nature and function of the three miniature eyes (ocelli) on the top of the head; about the nature of a wing vein and how the wing is dried when the adult insect emerges and about the function of the sting. One participant drew the subtle differences between the eyes of several wasp specimens, (Fig.16.a) while another drew general differences in the heads of two specimens (Fig.16.b). Figure two demonstrates an effort to highlight that one species had rounded and protruding bulky eyes, while the other had smaller eyes which imparts more space between, producing a wider 'face'.

> Drawing made me aware of the need to observe more and more closely with each stage of the drawing (Artist)

Some participants chose to draw the whole body, drawing characteristics in a more 'artistic' way – and then zooming in on particular features that claimed their attention, conveying the delicacy or geometry of the wings (Fig.16.c) or experimenting in transforming wings into delicate leaves through drawing (Fig.16.d).

In the afternoon session of the workshop, I presented my own investigation into the use of drawing in contemporary zoology. I reported on the qualities that make drawing valuable as an epistemological tool in species identification (see Anderson, 2014) and presented my own Isomorphology study as an example of an artistic approach to classification.

The participants were invited to consider this alternative and visual system for the continuation of their drawing practice. Looking for 'species' of form in different specimens helped to distinguish different structures in the wings and bodies of the wasp specimens. One participant drew the wings as a composite of hexagons, pentagons, squares and triangles based on the Isomorphology form set (Fig.16.c) and said: 'applying the Isomorphology forms and symmetries was very helpful in suggesting aspects to consider and encouraged thorough observation' (Photographer).

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38 Hamuli are small hooklike projections at the end of the wing bones.

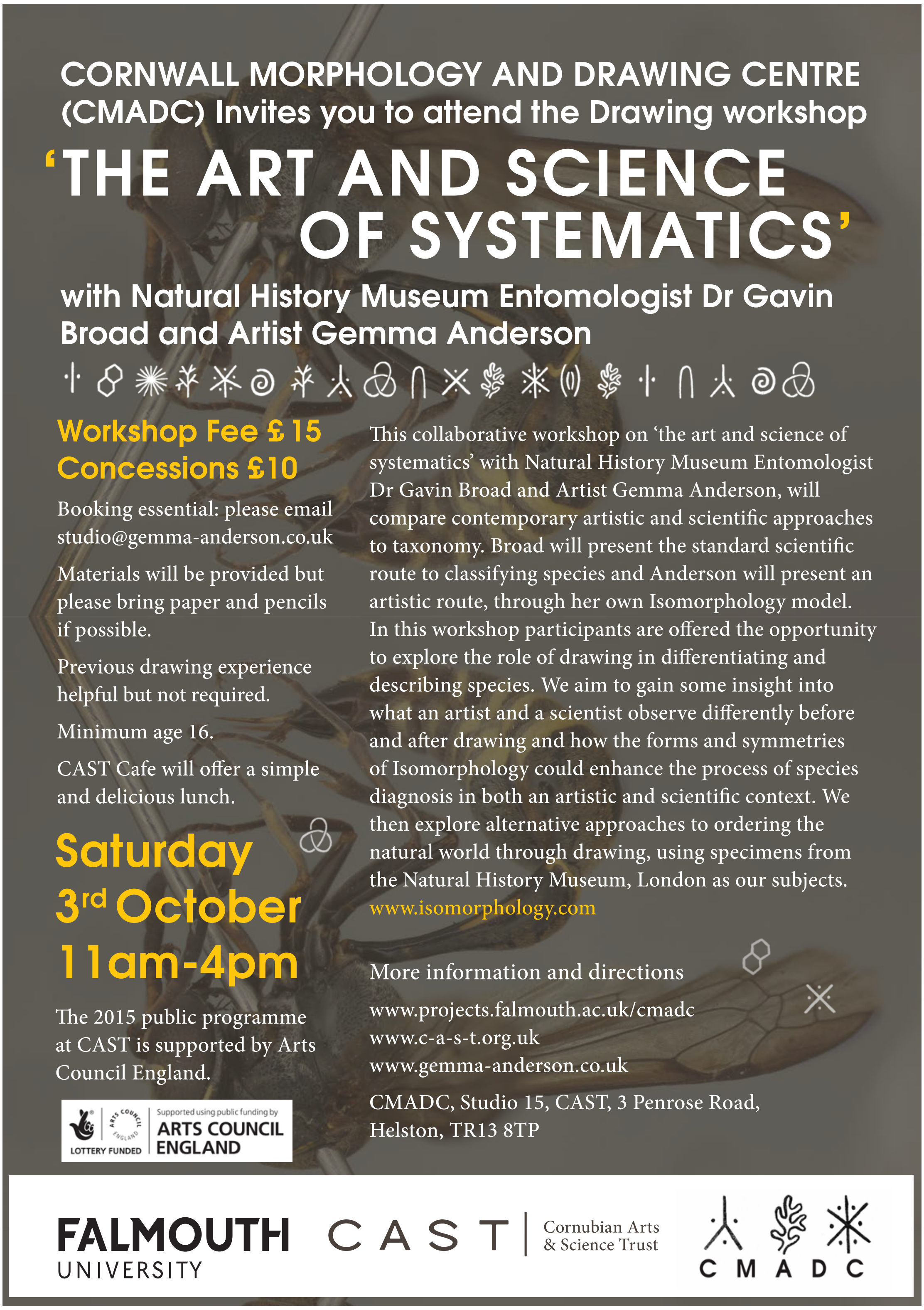
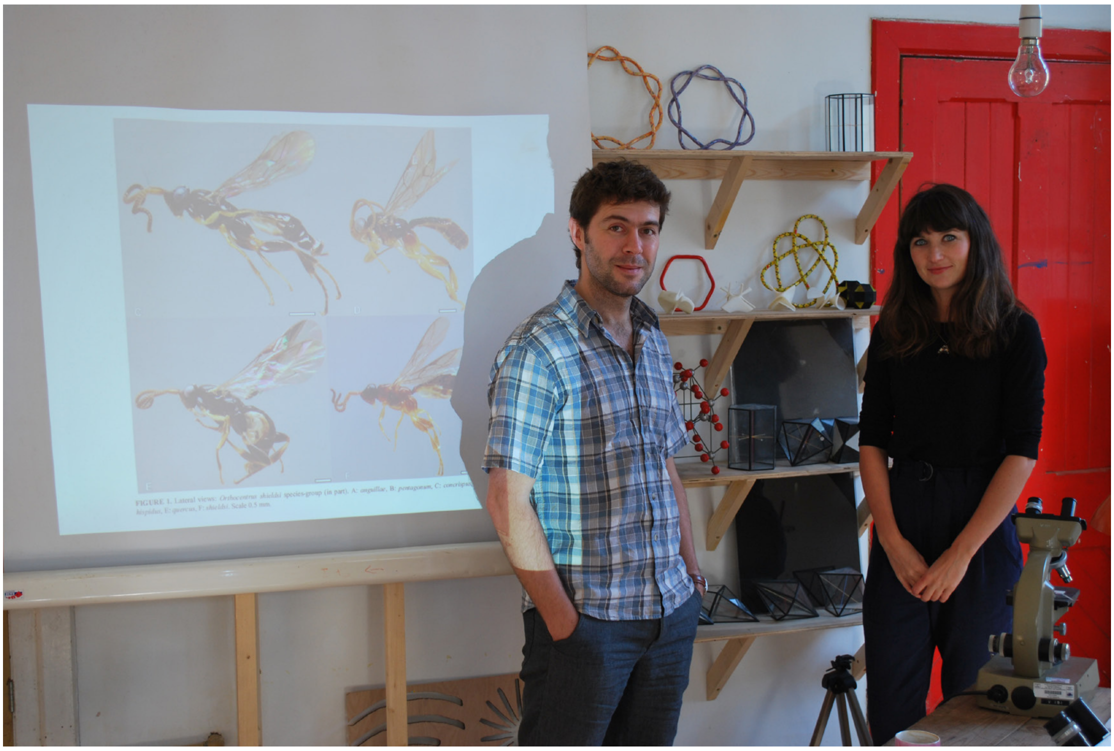


Figure 14.
KILBURN, John, 2015. Poster for 'The Art and Science of Systematics' workshop.



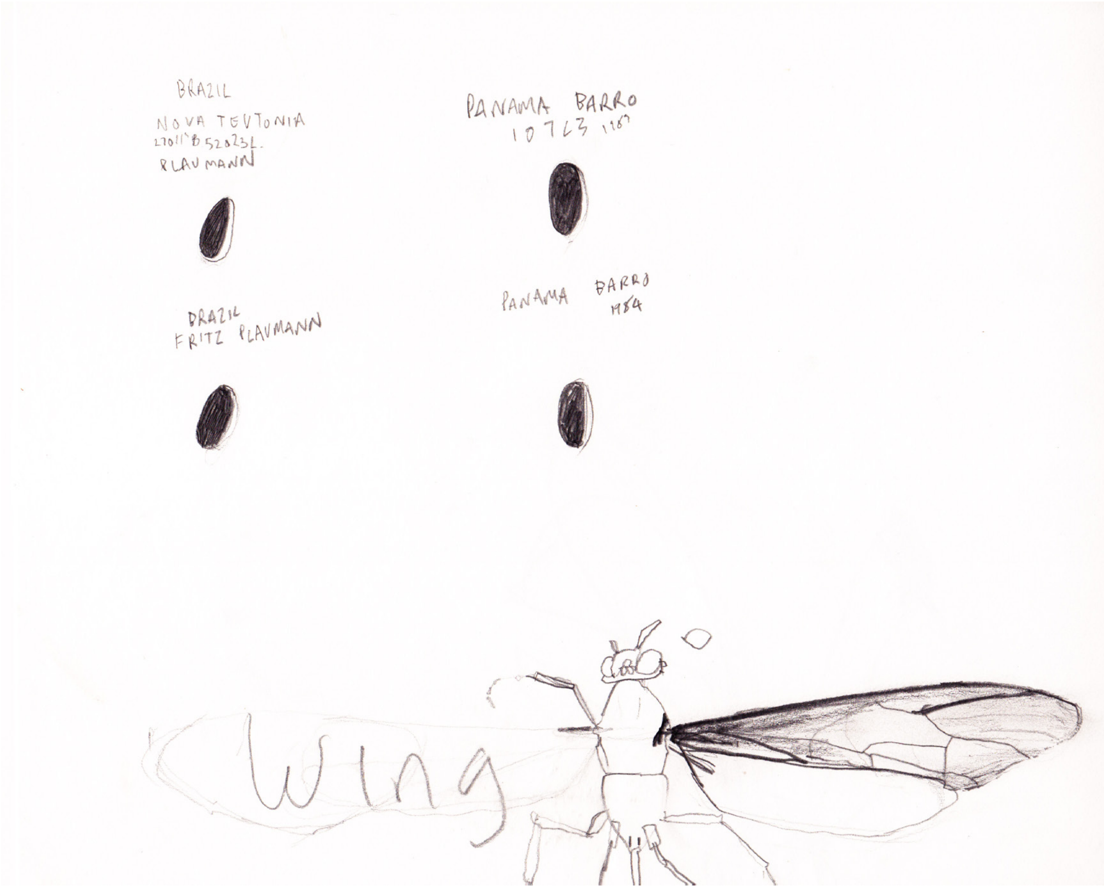
a.

b.

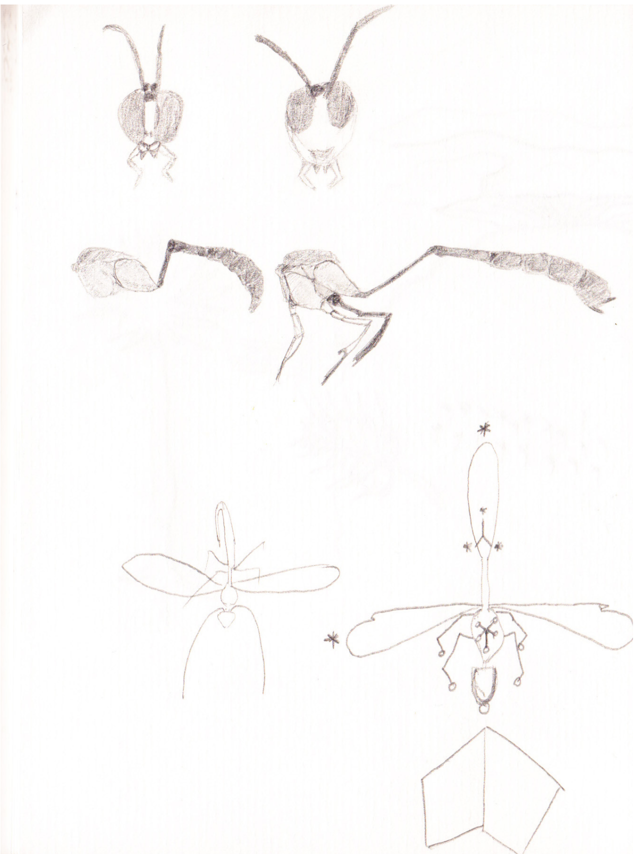
c.

d.

Figure 15 (a,b,c and d)
TEMPINI, Niccolo, 2015. Cornwall Morphology and Drawing Centre, Images from 'The Art and Science of Systematics workshop'. Photograph.

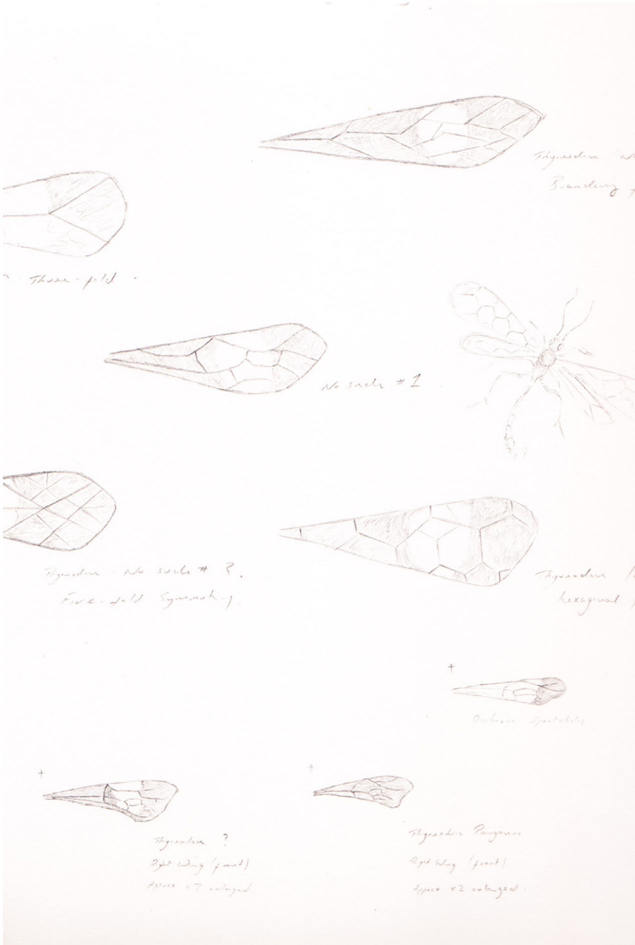


a.



b.

Figure 16.a.
Participant, 2015. Cornwall Morphology and Drawing Centre, The Art and Science of Systematics workshop, participant drawing of specimens. Photograph.
Figure 16.b.
Participant, 2015. Cornwall Morphology and Drawing Centre, The Art and Science of Systematics workshop, participant drawing of specimens. Photograph.



c.

d.

Figure 16.c.
Participant, 2015. Cornwall Morphology and Drawing Centre, The Art and Science of Systematics workshop, participant drawing of specimens. Photograph.
Figure 16.d.
Participant, 2015. Cornwall Morphology and Drawing Centre, The Art and Science of Systematics workshop, participant drawing of specimens. Photograph.

Reflections

Drawing helped participants to observe morphological features, to investigate the specimen as a complex creature, and to ask questions about the function of features. Drawing also helped to sustain and develop the observation of specimens.

In hindsight, Broad commented that the workshop had helped him to understand the role and value of drawing as a way of engaging people with taxonomy. Drawing helped the participants to eventually pick up on taxonomically important features, even if they did not know that they were the sort of features that a taxonomist might use.

> It is encouraging that a keen eye can discern meaningful characteristics and differences without a background in detailed morphology and terminology. However, it was also notable that attempts to draw wings, of pinned specimens were not as scientifically accurate as those drawn from microscope slides because the wings of a pinned insect are generally folded and bent to some degree, so interpreting the veins and cells is very difficult without a background knowledge of what a wasp wing looks like (Broad, 2015, personal communication).

Drawings of wings and the postures of specimens emphasised that the specimens were being depicted, not species.

There were clearly different ideas about what it means to compare specimens of the same or different species. The separation of specimen-level (intra-specific) from species-level (inter-specific) variation is usually difficult for the taxonomist, especially when working with small numbers of specimens. The closer the examination of fine details, such as eyes and faces then the better chance of distinguishing similar species. But differences and similarities are manifest at the micro- and macro-scale. The drawings produced gave rise to a diverse range of 'extra-scientific' interpretations, several participants sketched the specimens from different angles and perspectives, imparting a liveliness to the specimen and portraying its general shape and nature very effectively. Broad felt that some participants were better than he is at discerning and describing (in non-technical language) differences in overall form, or morphology.

Applying Isomorphological principles to the drawing exercise helped participants to understand that there is a pattern and geometry to the cells of an insect wing. The workshop allowed artistic and scientific questioning of specimens through observational drawing that can be developed for artistic or scientific work.

> From the viewpoint of engaging people with science, drawing workshops such as this are useful in introducing potentially difficult and arcane practices of taxonomy to people who would never usually have an opportunity to delimit species and describe the differences between previously unknown organisms. Invaluable, given the huge task ahead of us in describing the world's fauna and flora (Broad, 2015, personal communication).

Conclusions

CMADC has shown that the methods created through this research do not depend on being practised by me for them to be viable. The workshops have demonstrated that the drawing methods developed through this research are valuable as a cross disciplinary way of knowing. Each participant practises the method based on their own knowledge and experience and this is reflected in the developmental stages of their own drawing process: like each blade of grass grows differently, each drawing evolves differently and is always a variation on the method. This variation of approach and understanding further enriches my own understanding of the methods. In line with this, when I practise the method, the process and outcome will be different from another person's and show the methods potential to be personal but also sharable. The drawing methods shared through the workshops have not aimed to be 'personality neutral' like many 'traditional' methods of natural science but instead recognise the potential of an individual approach, as enriching and adding value to the study exactly because people are different. The methods work on the basis that individual personality is not a liability of the learning process but an important part of the creative work.

The Centre has built on the support of several regional institutions, including the Biosciences Department and Camborne School of Mines at the University of Exeter, Penryn and Falmouth University. The project has also hosted two Falmouth BA Drawing students for work placements and appointed a Falmouth BA Drawing student project assistant (see Appendix D.5). The activities of CMADC have led to a successful application to present Isomorphology as a way of navigating the tropical Biome at the Eden Project during the 'Strange Science' event in May 2015 (See Appendix A).

The Campaign for Drawing have supported CMADC through their social media campaign and publication about the launch event on their blog, which led to an invitation to offer similar workshops at the RCA Drawing studio summer school in 2015. Based on the innovative art/science collaborations and educational element of the project, the Northern Ireland Science Festival have invited me to be their first artist in residence in 2016. Corti and I will further develop the workshop we delivered at CMADC through an invitation by the Science Museum London to present a drawing-based event during the Mathematics festival in November 2015.

This project has also fed back into Teresa Gleadowe's vision of CAST, and as a result, Gleadowe has integrated the activities of CMADC into an Arts Council application for a contemporary art event in Cornwall in 2016, called 'Fieldwork'[39], she offered the following reflections on the CMADC project:

> 'The activities and events Gemma Anderson has led for the CMADC project exemplify exactly the kind of art/science dialogue CAST wishes to support. I have been impressed by the range of people from different backgrounds who have participated in the workshops, and by the liveliness and depth of the exchange. These workshops are clearly of real interest to the scientists as well as to the artists involved. I was fascinated to learn that Prof. Alessio Corti uses drawing to support his work as a mathematician and to hear Dr. Colin French talking about the importance of drawing in the identification of botanical species. The CMADC workshops appear to bring reciprocal benefit to both artists and scientists to an unusual degree. (Teresa Gleadowe, 2015, personal communication)

The questions addressed in this research demonstrate a strong epistemological motivation that is supported by the dissemination of the drawing methods at the Cornwall Morphology and Drawing Centre. CMADC has created a space to further explore artistic and scientific practices outside of the institutional space and offered ways of knowing the natural world that permit a freedom for art as education. CMADC has brought important aspects of my artistic research together in one place and represents my own particular approach to the artist's 'studio'. As my practice as an artist merges with my role as an academic, the exploration of the conditions that support drawing as a way of knowing; environmental, social and educational have become especially important.

As I discussed in opening this chapter, CMADC contributes to contemporary practices that consider artwork as an educational medium. As one of the proponents of the 'educational turn' (Wilson and O'Neill: 2010), Gillick notes: 'in exhibitions and biennales

39 CMADC has also led to further collaborations with the University of Exeter and to an application for annual fund application with Kathryn Moore (see appendix csm).

in recent years there has been a move towards including quasi-educational projects – not as add-ons but as an integral part of artistic production' (2008). This research shares many characteristics of practice situated within the 'educational turn', combining strong educational motivations and an interest in sharing artistic *process* rather than *product*. It contributes through presenting and discussing methods that develop a way of seeing and understanding the morphology of animal, vegetable and mineral in the context of collaborative interdisciplinary workshops that are led through an open dialogue between participants, myself and the collaborating scientist.

CMADC has become a productive outcome of this research, as it has produced a sustainable legacy through the web archive 'The Cornwall Morphology and Drawing Centre' (Anderson, 2015c) and the article 'Drawing the Real and the Unknown' (Hernly, 2015b). Specifically it produces a legacy 'in the world', with many people (from a wide variety of disciplines and backgrounds) adopting the methods and philosophy I have developed in their own scientific and personal understanding. At CMADC, society becomes part of the material for the artistic experiment; the world comes into the studio and the only way to know if the methods transfer is to test them, unrehearsed and live in action. CMADC has also produced a legacy for my 'future self' as an artist, as the participants, as well as collaborators, have actively contributed to the direction my own art will take in future years.

Chapter Ten

Conclusion

I propose that the argument for drawing as a way of knowing is best nested within a pluralist approach to epistemology. There are many possible ways to approach any subject and it is critical to identify particular areas where drawing has advantages to avoid the general claim that drawing can help us to 'know' without any direction.

With multimodal ways of knowing, it is important to give each mode its due. Reading, writing and arithmetic have advantages to learn and communicate about many things and so does drawing. It has been suggested that drawing should be considered as the fourth 'R' – or as 'visual literacy' (John Debes, 1969) but it remains challenging to introduce this in mainstream education as the linguistic system is clearly favoured in western society.

To strengthen the case for drawing as a way of knowing, it is now important to ask questions such as 'what particular aspects of science benefit from drawing' 'in what areas of science would drawing be useful?', 'what can be known through drawing and how this can be achieved'. This question invites further research about which specific areas of science drawing can be applied to gain further insight into the phenomena of study.

In this thesis I have presented a case for drawing as epistemology for morphology through a set of specific drawing methods. I propose this research can be further developed as enquiry into the natural world via the disciplines of biology and mathematics to study biological process.

The following research questions have formed the basis of this study:

1. What contribution can an artist make towards achieving a new understanding of morphology (animal, mineral, vegetable) for both artists and scientists?
This study explored representational and analytical methods of using drawing in collaboration with scientific practices and instrumentation.

2. What shared morphological characteristics (form and symmetry) of animal, mineral and vegetable species can be identified, known and represented through the process and object of drawing? And how can this research develop an extra-scientific model of classification that is complementary to the scientific approach?

The methods and artworks created and shared through this research have addressed these questions, using the variety of approaches outlined in the chapters of this thesis. All three unique drawing methods – Isomorphology, the Goethe inspired method and Isomorphogenesis – have been shared through workshops that have provided new ways of knowing morphology for both art and science. The epistemic value of drawing as process and as object has been apparent throughout in the form of exhibitions, publications and workshops with national and international institutions. Further to this, as documented throughout this thesis, scientists have acknowledged the changes that these drawing methods can bring to scientific practice.

I will now offer a short summary of the thesis as a reflection on how my practice, and the theory that accompanies it, have provided answers to my research questions:

Chapter one set a context for the contribution of this research to the fields of 'Drawing Research', 'Art/Science' and within the theme of the 'Educational Turn' in contemporary art practice. This thesis demonstrates a contribution to each of these fields whilst also connecting the fields in a novel way.

The second chapter of this thesis, 'Methodology', establishes a rationale for drawing as a research method through an in depth analysis of the characteristics that make it suitable for morphological study and as a collaborative and interdisciplinary tool. The key features of the methodology, as chapter two outlines, have evolved with the practice, and this evolution is reflected in the subsequent chapters of the thesis.

The third chapter, 'Drawing in Science', explores the epistemological value of morphological drawing in a contemporary zoological context and a contemporary mathematical context. Combined, these practice-based studies give a unique perspective on the role of drawing in contemporary scientific practice in different disciplines and in different modes of observation, mediation and technology. To complement the first study of drawing in zoology, which is embedded within empirical science and observational methods, the second study 'On Drawing and Mathematics […]', moves from direct observational methods to a more conceptual approach. This shows drawing as both an individual and a collaborative tool for 'thinking-through' questions of form in mathematics, and as a way of creating and sharing knowledge across disciplines. Together, these studies provide a background for chapter four, which explores drawing as an epistemological tool for developing morphological insight in my own practice.

Chapter four, 'Drawing Resemblance and Isomorphology', examines the significance of resemblance in my own drawing practice, not construed as something inherent in the world, but as a relationship that is discovered through the process of drawing. This chapter argues that drawing can provide a means to shift the boundaries of traditional classificatory practices and can reveal morphological resemblances between animal, mineral and vegetable species. Throughout this chapter, an argument for pluralist and visual approaches to classification is developed. This is demonstrated through Isomorphology, my own practice-based investigation of the shared forms and symmetries of specimens in the collections of the Natural History Museum, London.

Chapter five, 'Drawing with Goethe's Morphology', relates Isomorphology to Goethe's original concept of morphology and describes my own adaptation of Goethe's morphological approach to create a new drawing method. This new drawing method then develops and redirects Isomorphology from the study of form and symmetry in whole organisms, to parts of organisms, thus initiating a move from observation to abstraction.

Chapter six, 'Dynamic Form: Klee as Artist and Morphologist', proposes Klee as a morphologist within the framework of Goethe's morphology, a proposition that is supported by accounts of his interactions with the science of his time and his teachings at the Bauhaus. Images are central to the argument that Klee's work reveals morphological insight into the dynamic nature of form and are important to my interpretation of his work as a visual counterpart to aspects of Goethe's morphology. Positioning Klee as an artist and morphologist supports my argument for drawing as epistemology for morphology in both artistic and scientific practice.

Chapter seven, 'Notes from an Artistic Collaboration', offers further insight into how collaboration has informed this practice-based research. This short chapter – an interlude – marks a shift in the direction of the research. This chapter documents my experimental collaboration with mathematician Alessio Corti and explores how the use of analogy and metaphor can enable a shift from an observational to a conceptual understanding of natural form. Combining the influence of Klee and my collaboration with Corti, I then make a conceptual leap in my own drawing practice towards representing the dynamic nature of form.

Chapter eight, 'Isomorphogenesis: Drawing a dynamic morphology', presents my own exploration through drawing of form as a dynamic and time-based process. In this chapter I reveal how the influences of mathematics, Klee, D'Arcy Thompson, William Latham, John Dupré and the conceptual science of Theoretical Morphology lead to the development of 'Isomorphogenesis', a drawing based algorithm informed by biological principles. This chapter explores the 'liberation' of my own drawing practice from an observational to a more theoretical approach to morphology.

The final chapter on the Cornwall Morphology and Drawing Centre (CMADC) marks the culmination of the practices and collaborations described throughout the thesis. A series of public drawing workshops in collaboration with scientists, working in the disciplines of mathematics, botany, mineralogy and zoology, have shared the methods developed through this research for drawing as epistemology for morphology. Each workshop integrated elements of the methods described in the chapters: 'Drawing Resemblance and Isomorphology', 'Drawing with Goethe's Morphology', 'Notes from an Artistic Collaboration' and 'Isomorphogenesis: Drawing a Dynamic Morphology'. As evidence of the transferability of the drawing methods developed in this research, CMADC and its activities provide one possible form of 'legacy' for this PhD.

Another form of 'legacy' for this PhD is future research. Through Isomorphology and Isomorphogenesis, I have developed a classification of form and methods for representing form and formative process. These methods develop observational and conceptual techniques for the art and science of morphology. An objective of future research is to extend parallel techniques to the observation, appreciation and representation of form as something in constant flux. Form is responsive to its biological and environmental context, and therefore should be understood appropriately in relation to the always-dynamic nature of biological reality. I will bring together my experience of working with scientists on the potentialities of drawing, with Dupré's ERC-funded project, 'process philosophy for biology'; this would provide, in effect, a drawn classification of biological process. I plan to submit a post-doctoral application early 2016 for beginning research late 2016 to explore new questions about processes that have emerged through this research.

This future research will explore education as an artistic medium, building on the practices of The Cornwall Morphology and Drawing Centre, Isomorphology and Isomorphogenesis and focusing on biology-as-process. The workshop method will continue to have an important role and provide opportunities for participants to co-create meaning alongside the artist. These workshops will aim to reveal the production of art and knowledge – object and process – equally to the participant and the viewer as to the artist.

Current visualizations of biology-as-process exist mainly as computer, digital images or animations that allow the viewer to witness knowledge as it is presented rather than to create knowledge as the result of an epistemic process. Drawing offers a way to create and to own knowledge because human participation is necessary at every stage. I endeavour to develop further drawing methods to mediate and slow down dynamic processes into static images, including drawings, etchings and watercolours. These artworks will create impact through further exhibitions and publications, and will be continuously utilized as educational resources for a series of interactive drawing workshops that will further understanding of the nature and types of biological processes to a wider audience. The first experiments have been during a period as artist in residence at the Northern Ireland Science Festival in 2016, including a workshop, public talk and exhibition 'Drawn Investigations from Art and Science' at the Naughton Gallery, Queens University (see appendix A).

Reflections

1. Philosophy and art theory

While reflecting on the nature of my research, especially in this thesis, I have found James Elkins' classification of the different kinds of practice-based theses (Elkins, 2009: 145) helpful. I situate this thesis close to what he describes as 'philosophy or art theory' as opposed to an art historical, art criticism or 'thesis as art' approach. Under Elkins' framework this thesis can be considered as a philosophical and practical investigation into drawing as epistemology for morphology. Through this investigation I have collected idiosyncratic elements from many disciplines, mining both theory and practice for material that could used in this artistic research and further extracted from through drawing.

To complement supervisions, this research has utilised the resources of institutions of knowledge and learning - the university and the museum - and mixed science and the humanities in new ways. However, I wanted to avoid the danger of producing a practice so marginal that it could no longer take part in principal dialogues about contemporary art. The interdisciplinary nature of this research also positions it close to what Elkins describes as an 'art as science' approach, since it is research that exemplifies morphological practice – albeit in a creative way. By offering an interdisciplinary research model that integrates drawing into artistic and scientific practices, this research provides a critique of disciplinarity as the art and the science of morphology are intertwined at every stage of the research practice.

2. Objects and processes

What was surprising about the Isomorphology study was the generative nature of the enquiry. The lengthy observation of the shared forms and symmetries of animal, mineral and vegetable species led me to questions about formation. This in turn led to greater emphasis on how to represent the dynamic, generative nature of form. This shift from an object-view to a process-view of form reflected a change in my understanding of morphology and follows Goethe's original conception of morphology. This view avoids the reduction of phenomena to either structure or process but allows both into the art and science of Morphology. This shift in understanding was a development that I had not anticipated and increased the remit of this project.

3. Art/Science and the critique of disciplinarity

The drawing methods developed in this research allow artistic and scientific approaches to converge and then to diverge, blurring the edges between artistic and scientific practice and, therefore, transcending the boundaries often associated with the 'two cultures' (Snow, 2012). Philosopher of Science Chiara Ambrosio (UCL) has described this research as 'artistic visualization as critique' (Ambrosio, 2014: 134-137) and suggests that it should be taken seriously by artists and scientists alike, especially in a time of interdisciplinary art/science collaborations and artist-in-residence programmes. Reflecting on the Isomorphology series, she says:

Gemma's work is quietly controversial. The silent space of observation, the simple and tacit gestures that accompany it, offer a frame and a context for reassessing aspects of our knowledge that are taken as self-evident, established and in no need of further elaboration. If science intends to continue to take pride in its fallible attitude and pose it as a model and a value for other forms of knowledge, then it should cherish the challenges and opportunities that Isomorphology discloses. In interrogating foundational aspects of science- observation, classification, representation, experimentation- Isomorphology interrogates the limits of our knowledge and directs our scientific gaze toward new questions, new practices and new challenges (Ambrosio in Anderson 2013h:7). Through the creative exploration and observation of individual specimens the practice of Isomorphology draws parallels with the scientific practice of taxonomy, but, importantly, it offers an alternative visual approach to classification that does not rely on names or numbers. Isomorphology shows that there are many ways to explore and organize natural form through a creative expansion of the categories currently used to make sense of the world.

4. Scientific knowledge

Isomorphology has contributed to morphological knowledge through asking and answering questions that scientists do not often address, such as 'what animal specimens have spiraling morphology?'. Through the medium of art the Isomorphology, Goethe and Isomorphogenesis methods have become means to communicate the findings of this research to a larger audience. The collaborative nature of this research has impacted the way that some scientists now see their own practices, as quotations in chapters four, five, eight and nine testify. Gradually, certain scientists have come to take the Isomorphology project seriously (French and Broad for example). They now appreciate the practice of Isomorphology as an epistemic ethos built on an artistic practice that incorporates the scientific approaches of handling specimens, working with microscopes and experimenting with new hypotheses. Isomorphology is a blending of scientific and artistic experimentation that brings with it new modes of seeing and classifying the natural world.

Artists and scientists both look for ways to practice theory using different approaches. The production of knowledge in this research has been inextricably linked with experimentation, and has depended on experimental and material set up, also crucial to knowledge-making in science. By placing observational drawing at the centre of my own artistic experimentation and method, and by sharing these methods with others, I have demonstrated that drawing is still very much alive as an epistemic process - as a way of producing knowledge.

5. Drawing methods and workshops

The drawing methods developed through this research have formed the basis for my engagement with artists, natural scientists, students and the general public through participatory workshops, conferences, publications and exhibitions, culminating in the development of the Cornwall Morphology and Drawing Centre (CMADC). As a method in itself, the workshop employs drawing as a means to know things which would otherwise escape notice or be difficult to express through language. Workshops have deepened the engagement between drawer and the nature of animal, mineral and vegetable forms and have increased empathy for the natural world in the process. I consider the drawing methods as successful, based on verbal and written feedback from participants and the drawings created in both art and science contexts. Workshops have therefore been central to the evaluation of the epistemological value of drawing in this research.

I embraced the public positioning of this work because it encouraged and enabled valuable spontaneous dialogue. The workshops emerged out of an aim to share drawing as a way of knowing with others, and have developed to suit each location and group of participants. The practice of delivering the workshops has helped me to articulate and to reflect on my own methods, and to position this artistic research as an educational practice and as a model for 'art as science' or 'art as morphology'.

The development of the workshops has allowed me to understand how the methods could be explored further. While the impact of this research is hard to measure (and would require methods that exceed the scope of this research), feedback from the workshops has directly influenced the workshops and research that followed. This generated a productive tension between the challenge of quantifying the impact of my methodology, and the individual, qualitatively different responses that the drawing methods prompted in different participants. The tension is productive precisely because it defies "objective" criteria of measurement and opens up novel ways of interpreting impact.

As something I have been personally invested in for many years, I have been moved by how much 'drawing as a way of knowing' means to others. The drawing workshops at CMADC have brought disparate groups of people into intimate situations. In general, participants have found being able to develop and share drawing methods that have a genuine impact as a creative way of knowing to be a genuinely rewarding experience. The workshops have brought an audience of curious and visually interested people, and offered process-oriented drawing activities based on learning and sharing rather than producing any 'art' object.

On Drawing as Epistemology for Morphology

In this thesis I advance the philosophical point that drawing is an epistemological tool for morphology and that the knowledge produced through drawing can offer new ways of

thinking about morphology and scientific classification.
Drawing generates a distinctive form of knowledge because it aligns internal duration with external representation. A drawn representation of form-change as a connected continuum enables both the drawer and the viewer to see developmental stages simultaneously, enabling comparison and understanding.

The necessary state of being present in the observational drawing process erodes boundaries between observer and object. My research has shown that particular drawing methods promote a deep engagement with biological form and process: Drawing has the power to mediate, translating observation and understanding of the world through an interaction between perception and reflection.

Drawing has played an important role in the communication between myself and natural scientists and mathematicians, often acting as a shared language. As a way of knowing, drawing can generate ideas and sometimes demand pauses mid-conversation to make notes or draw an image that has arisen. While this collaborative process deviates in many ways from traditional processes of an individual making an art object, it enables a freedom to break away from the pre-existing role of the artist in the studio and to react to and interact with science.

My collaborations with scientists have resulted in joint publications, presentations, involvement in public and intellectual life, and discoveries that have mutually fed back into our research. This aspect makes these collaborations remarkable and different from the collaborations where one visits the other, spend some time together, talk about things, experiment, but then the artist produces their own exhibition and the scientist presents research at an academic conference. In these collaborations, art and science have joined and created a new culture in doing so. Evidence of this is both in the informal, personal exchanges with scientists I have used throughout the chapters, and in the formal, published outputs that show this dialogue with science has been validated and recognised through the peer-review process.

This research shows that drawing does not merely illustrate scientific concepts: It is a way of producing knowledge. This artistic research prompts a constructive critique of the assumptions and modes of working that scientific practitioners often take for granted. For example, the focus of drawing's epistemic value in science is generally around the drawing as object and not the drawing process itself - figures are used to illustrate, to show things, to objectify things. It often is not clear if the image has been produced by a scientist, an artist or an illustrator, and this is rarely considered an important detail. That the process of drawing has epistemic value for scientists (Anderson, 2014a; Anderson et al, 2015) has been overlooked by science. This research shows that drawing has currency as a means of scientific discovery and advancement of knowledge, and re-imagines a scientific practice where drawing is valued as part of creating scientific knowledge rather than simply as a service to scientific knowledge and communication. It is clear that an immediate problem with this idea is the subjectivity of the process of drawing, which does seem to conflict with the idea of the 'objective' work of science. I argue that it is precisely the attention paid to the subjective process of creating a drawing, along with the ideas, analogies, and metaphors that an image can hold, that enriches scientific practice (Anderson, 2014a; Anderson et al, 2015). This is not a suggestion that all scientists become artists, or that all scientists draw, but an argument for the value of drawing as an epistemic object. I believe that placing greater value on the process of image creation in science – especially drawing – could transform the relationship between scientific word and image.

With this research, the hope has been that this piece of work can be a useful contribution to others who live through similar questions. More generally, I anticipate a contribution to our public culture – which has always immensely benefited by pluralism and positions that try to shake the inertia of established ways of thinking and knowing. I consign this thesis to the future as a demonstration of drawing as epistemology for morphology and as a vehicle for sharing morphological insight and practice. I look forward to the continuation of this work.

Glossary

Algorithm: a set of steps that are followed in order to solve a mathematical problem or to complete a computer process.

Allometric: in studies of ontogeny, denotes a particular type of growth in which the relative growth of two different aspects of form in an organism follow a power function of the type.

Allometry: relative growth of a part in relation to an entire organism or to a standard; also : the measure and study of such growth.

Anisometric: in studies of ontogeny, denotes growth processes in which an organism's form or proportions change with time.

Bauplan: German engineering term translated simply as blueprint. In biology the term is used to represent the basic architectural and organizational pattern shared by the members of a monophyletic clad of higher taxonomic rank.

Botany: a branch of science that deals with plant life.

Cayley Graph: A representation of a group of symmetries as a network, where each node in the network represents a symmetry and paths in the network encode composition of symmetries.

Chimera: a monster from Greek mythology that breathes fire and has a lion's head, a goat's body, and a snake's tail.

Crystallography: a science that deals with the forms and structures of crystals.

Cytology: the study of plant and animal cells.

Epistemology: the study or a theory of the nature and grounds of knowledge especially with reference to its limits and validity.

Euler Formula: In three dimensions: the equality V-E+F=2, where V is the number of vertices of a three-dimensional solid, E is the number of edges, and F is the number of faces. In four dimensions: the equality V-E+F-T=0, where V is the number of vertices of a four-dimensional solid, E is the number of edges, F is the number of faces, and T is the number of three-dimensional facets.

Fano Variety: Fano Varieties, roughly speaking, are "atomic pieces" of higher-dimensional geometrical shapes. In precise mathematical terms, they are smooth projective complex manifolds with ample anticanonical line bundle.

Inverse Vision: Turning an internal spatial understanding back into a two-dimensional image.

Genealogy: the study of family history.

Gnomic growth: growth in which each new growth increment or unit is a gnomon to previous growth increments or units - that is growth takes place without any change in shape.

Heterogeneous: made up of parts that are different.

Heterochrony: deviation from the typical embryological sequence of formation of organs and parts as a factor in evolution.

Holotype: the single specimen or illustration designated as the type for naming a species or subspecies or used as the basis for naming a species or subspecies when no type has been selected. Also called type.

Hybrid morphospace: a morphospace containing both empirical input data, taken from actual specimens and theoretical model parameters, which are used to manipulate the input data in a theoretical fashion to produce a hypothetical spectrum of form. Such a morphospace is technically neither empirical nor theoretical but a mix of both.

Hypermorphosis: The principle that developmental patterns tend to change more by terminal or subterminal addition than by substitution, omission, or preterminal addition.

Hyperspace: a conceptual space, as opposed to experiential space, whose dimensionality usually exceeds three dimensions. Cyberspaces are usually defined mathematically though this is not a formal requirement.

Inorganic: made from or containing material that does not come from plants or animals.

Isometric: in studies of ontogeny this denotes growth processes in which an organism's form in proportion does not change with time.

Linear Logical Thinking: The sort of reasoning that constitutes a mathematical proof.

Logarithmic: a number that shows how many times a base number (such as ten) is multiplied by itself to produce a third number (such as 100).

Mineralogy: the scientific study of minerals.

Molecular biology: a branch of biology dealing with the ultimate physicochemical organization of living matter and especially with the molecular basis of inheritance and protein synthesis.

Monodromy: A measure of the twisting of a shape as you move around a loop in the parameter space for that shape.

Morphology: the study of the form and structure of animals and plants.

Morphogenesis: the formation and differentiation of tissues and organs.

Neoteny: retention of some larval or immature characters in adulthood.

Neologism: a new word or expression or a new meaning of a word.

Ontogeny: description of the growth and development of changes that take place in the life of a single individual organism.

Parameter Space: Mathematical shapes can depend on "deformation parameters." Changing these parameters changes the sizes and relative positions of different parts of the shape, but leaves the qualitative form of the shape unchanged. We can think of a single shape (with fixed deformation parameters) as giving a point in the space of all possible parameters, which is called parameter space.

Particle physics: a branch of physics dealing with the constitution, properties, and interactions of elementary particles especially as revealed in experiments using particle accelerators —called also high-energy physics.

Phenotype: the observable properties of an organism that are produced by the interaction of the genotype and the environment.

Progenesis: precocious sexual reproduction.

Reticulum: a reticulate structure or network.

Rotring pen: a technical drawing pen.

Setae: a stiff hair, bristle or bristle-like process or part of an organism.

Species: a particular group of things or people that belong together or have some shared quality.

Taxonomy: the process or system of describing the way in which different living things are related by putting them in groups.

Topology: a branch of mathematics concerned with those properties of geometric configurations (as point sets) which are unaltered by elastic deformations (as a stretching or a twisting) that are homeomorphisms.

Wheal: cornish word for mine.

Zoology: the branch of science that involves the study of animals and animal behavior.

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Appendix A: Isomorphology at the Natural History Museum

This appendix supports chapter 4 'Drawing Resemblances and Isomorphology', with material about the Isomorphology practice at the Natural History Museum and talks, exhibitions and workshops which shared the Isomorphology practice and drawing method. The following sections are indicated at different points in chapter 4.

A.1: How drawing process at the NHM began:
A.2: Accounts of drawing process during the Isomorphology series at the Natural History Museum (NHM)
A.3: Selected lists of the specimens drawn in the Isomorphology etchings:
A.4: Examples of the different nature of Isomorphology workshops
A.5: Images of compiling Isomorphology publications
A.6: Images of Exhibitions and Public Talks:
A.7: Reflections from a Scientist: 'Symmetry and Isomorphology' by Peter Tandy
A.8: ERICA Prototype Plant Identification Key including Isomorphology (by Colin French)

A.1: How drawing process at the NHM began:

Working with NHM
As a postgraduate student at the Royal College of Art (2005-2007), I attended an 'Anatomy for Artists' course at University College London that introduced me to the human anatomy collection at UCL. During this time, I started drawing from other collections at UCL, including the Grant Museum of Zoology and 'The Rock Room' mineralogy museum. To complement this study of animal and mineral morphology, I initiated and pursued opportunities to draw from Kew Gardens' research collections. This practice, which necessarily involved many conversations with scientists and curators, provided contacts that helped me to build a relationship with the Natural History Museum. In 2012, after a six-year unofficial relationship with the NHM, I proposed the Isomorphology study to Julie Harvey (Head of Centre for Arts and Humanities Research at the NHM) and Clare Valentine (Life Sciences, NHM). With their support for this study, I began drawing in the Angela Marmot Centre in October 2012. In December 2012, it was agreed that I could draw specimens (which needed to be transported from their normal location in the collections) in the Sackler Imaging Lab[1] in the Darwin Centre. This agreement lasted for the 18-month duration of the research practice (December 2012 to April 2014). The following text details the process of creating the Isomorphology image series. The following is just one example of the meetings I have had at the NHM since 2006. I have selected this example because, although directed by my survey of form, it shows an example of the surprising discoveries that informed the study.

1 The Sackler lab is a secure space for temporally storing specimens and has natural light for drawing.

Notes from Isomorphology practice: Journal Extract: 05/12/12 Meeting with Alison Paul, Curator of Ferns:

'I met Alison Paul by the giant sequoia and we enter the Cryptogamic Herbarium on the second floor of the museum building. Inside there are hundreds of mahogany cabinets filled with pressed botanical specimens. Alison is the curator of the fern collection and we discussed what kind of specimens I would like to look at. We spent a couple of hours looking through pressed specimens from the collections, some very inspiring, and I got a very good insight into fern diversity. First we looked at the horsetail 'Equisetum', which I have previously worked with using the Scanning Electron Microscope. When pressed, the specimens reminded me of insect legs, with segments and spikes. All kinds of analogies came to mind as we looked through: ferns that looked like lungs, corals, seaweeds, and ferns that had already been nicknamed, like the Rashleigh minerals, based upon their resemblances to other species, for example 'Stag's Horn', 'Adder's Tongue' and 'Elephant's Tongue'. As I have been drawing scientific specimens for a long time, I could make comparisons between different ferns and crinoids, stick insects and starfish. With Isomorphology in mind I was looking out for symmetry and form, zig-zags, pentagonal, tri-radial, bilateral, branching, spiraling, hexagonal, four-fold and hyperbolic were all present'.

A.2: Accounts of drawing process during the Isomorphology series at the Natural History Museum (NHM)

What follows is a series of short texts[2] which I wrote during the process of creating the Isomorphology Etchings at the NHM. They are presented here as representative examples of the process:

Isomorphology practice day one: 31/10/12
I begin by drawing fourfold symmetry at the Angela Marmot Centre (AMC), after emailing Florin (Curator, AMC) a list of specimens identified as showing fourfold symmetry (Fig.A.2.1-A.2.7).

9.30am: Meet Florin at the AMC, select dragonflies, bees and wasps. Realise that in the selection process Florin is making the first decisions as he decides which cabinets and drawers to open before we make a selection of individual specimens. I begin with a good selection of bees, wasps and dragonflies.

10am: Peter Tandy (NHM Mineral Curator) calls over as previously arranged via email. He has selected mineral specimens which show fourfold symmetry, but tells me that he has asked his boss (Alan Hart, head of Earth Sciences Collections at the NHM) if he

2 Presented in italics as they have been transcribed directly from my notebooks.

could bring them for me to draw and Alan had told him 'not yet, I need to speak to Clare Valentine'. This is the first problem, Peter has been bringing specimens for me to draw in the various locations at the NHM since 2007 and this has previously not required Alan Hart's permission. Ironically as the arrangement to draw at the museum has become more official for the duration of the PhD research, and therefore should be easier, it is making the process more difficult during this early stage.

The next challenge arises when Mark Spencer (Curator of Botany, NHM) brings the specimens I had previously emailed to him as examples of fourfold symmetry. The specimens are in the form of dried and pressed herbarium sheets and it is not possible to see their floral symmetry, so in this case it is impossible to draw their visible fourfold symmetry. At this point, I realise the challenges of drawing three dimensional plants which have been pressed into two dimensional specimens and this requires that I reconsider my approach. I took a break and phoned Kew Gardens and spoke to Mark Nesbitt (curator of Bark at Kew) who advised me to speak to Begona (a herbarium curator at Kew) about access to live plant specimens. I send Begona an email and resolve that there is more groundwork to do when it comes to drawing plants.

I go back to drawing the specimens at the AMC, starting with drawing the dragonfly specimen and I observe that each specimen shows fourfold symmetry but through its own variation on the theme and many specimens look less like the form species than I expected. One challenge of this work is to make relations between these variations on the theme. The first stage of observation helps to find an angle to draw the specimen which shows the form and symmetry.

12.30pm: Peter Tandy returns with mineral specimens, this is very good news and I continue drawing the botanical, zoological and mineralogical specimens for the rest of the day.

Reflection on this first day of drawing:
Not having access to all specimens at the same time led to a new idea of how to draw specimens. Rather than drawing animal, mineral and vegetable (A,M,V) species into one body which I had previously imagined, I decided to proceed by drawing A,M,V into a landscape where it is possible to exchange parts, for example, the dragonfly becomes flower and the flower becomes dragonfly, mineral etc. This is how I continued to work on the first Isomorphology etching of 'fourfold symmetry'. In drawing related specimens into a landscape I use drawing to exchange and join bodies.

01/11/12:
After realising that this research may not be as straightforward as drawing specimens at the NHM from my list, I arrive at south Kensington tube station and look for flowers with fourfold symmetry (ad-hoc fieldwork) to bring to the museum to solve the problem of having

very two dimensional plant herbarium specimens to work with. I find the flower euphorbia and bring it to the AMC where I integrate the plant into my drawing. The drawing continues to surprise me as it evolves. My idea of the work is changing through the practice as the drawing shapes and re-shapes my original ideas.

14/02/13

<u>Drawing Spiral form species</u>

Arrive at 9.30am and meet Jon Ablet NHM curator of shells and molluscs at 'giraffe corner'. I select shells from NHM selection of cross section to draw. I then call Gavin Broad (Zoology Curator) who comes to collect the shell specimens with me. We then walk with the specimens to the Sackler Lab at the Darwin Centre. Ranee Prakesh (curator of botany collections) has left dried spiral plant specimens from the herbarium on her desk for me. I look through these specimens and begin to select which I will draw and organise into two piles in my lab space in the Darwin Centre.

I have also arranged to draw a shark's egg case with Zoology Curator James McClain and go to his office from where we go to the 'wet' collections to choose a dried shark's egg case (Fig.A.2.8) with spiralling morphology. Although I see a variety of wet sharks' eggs cases I chose the dry specimen because the spiral morphology is more visible whereas in wet specimens the spiral form has collapsed a bit. The difference between wet and dry specimens is significant in this study as it is often more difficult to see morphological structures in wet specimens, and it can also be more difficult to draw specimens which are within glass jars.

Back in my lab space at the Darwin Centre another curator of plant material, Jacek (NHM Botany curator Ranee Prakesh has asked Jacek to help me) calls in and asks if I would like him to help me find some spiral fruits in the collections to draw and I reply 'yes please'. Jacek calls back 15 mins later with a tray of intricate spiralling seeds (Fig.A.2.9). I look through these specimens and make selections and begin to draw them into the work. (Fig.A.2.10-A.2.14)

In drawing the spiral shark's egg case a face emerges unexpectedly, the face is framed by a hat and a moustache, I think of this as an example of morphology suggesting art. Following this play of resemblance I draw a spiralling plant as the arm, and Jacek brings me another spiralling specimen that looks like a hand, but he tells me 'it's a helix not a spiral' and he is right. Continuing the drawing, I let the forms 'play'; spiralling minerals and shells form a hill, and the image starts to look like a surrealist landscape, or a 'gestalt' image, once the figure is seen it is clear but it is not immediately visible. During lunch, in the common room at the NHM, an entomologist joins the conversation Gavin and I are having about spiralling forms and later in the afternoon, he emailed me a digital image from his research of a microscopic spider with a spiralling tail. Later that day I talk to Will Hunter who works in the education department at the NHM and we discuss proposing an Isomorphology themed 'Nature Live' (NHM Public event, Darwin Centre).

29/05/13

<u>Drawing Five-fold Symmetry</u>

I meet Tim (NHM curator of Paleontology) in the Paleontology department after emailing a list of blastoid and crinoid specimens with five-fold symmetry I would like to draw. We spend time selecting some specimens from the list (not all are available) and others which we find which are not on the list (Fig.A.2.15-A.2.19). When drawing crinoids, I am comparing my natural approach to the approach I have been developing inspired by Goethe. I find that I am progressing through some of the steps naturally in the Isomorphology drawing process which begins with observing form of specimen and describing morphology with drawing, which I learn as I go along. The main difference is that although I find the process of writing a detailed description helpful, I prefer to draw without using 'language/text' at all in the observational drawing process. As I get to know the form more through drawing I begin to draw without looking at the specimen, essentially making it up based on my practice of drawing the form from observation. This is a similar departure from observation as experienced in the Goethe method, but one which follows the natural order of the specimen's morphology. The next step is to imagine and draw a different order for the parts. This drawing experience helps me to understand the Goethe method as a natural progression of the Isomorphology method.

I reflect on how much potential for drawing each specimen contains. Drawing feels like taking notes from the specimen. Once drawn, I can refer to the morphology in the drawing, which is easier to read than the specimen, and then abstract from this to draw parts which can be recombined.

05/12/13

<u>Drawing Radial Symmetry</u>

I meet Andrew (NHM Curator of marine invertebrates) and we collect starfish wet specimens and equipment to de-jar specimens (we open the lid with the aid of hot water). As we look for specimens, we discuss ontogeny and stop to look in the Darwin library for a book on the embryology of starfish.

Later the same day, I spend a long time with Jacek in the herbarium. It is difficult to find some specimens but we encounter some nice surprises in the process as usual.

A.3: Selected lists of the specimens drawn in the Isomorphology etchings: Radial Symmetry

Zoology Specimens: labidiaster annulatus (large sladen), crossaster squamatus (dod), heliaster kubiniji, crossaster papposus
Botany Specimens: nymphaea gladistonisca (biggest flower drawn), anemone hortensis anemone appeneona (inside flower), hydrocotyle bonauenus
Mineral Specimens: barite (catalogue number 4019), pyrolusite (catalogue number 18810), quartz, wavellite (catalogue number 48003), hydrocotyle vulgaris (Palestine)
Three fold symmetry
Botany specimens: trillium erecta var alba (1328), malpiphialcs 32, Dioscorea
Mineral Specimens: Calcite, Chalcedony, Diatom, Ricinis communis (5973)
Branching Forms
Mineral Specimens: dendritic chalcedonic stalactites (catalogue number 92894), Trevascus mine, cornwall, 1860. Copper dendrites, lake superior (catalogue number 66610). Copper, bogoslovsk, (catalogue number 36611), Russia. Quartz- chalcedony (catalogue number 58573). Native copper cornwall (catalogue number 17838).
Zoology Specimens: Clemmys leprosa, lungs of a tortoise (catalogue number IM246), Chameleon vulgaris, lungs on chameleon (catalogue number IM73), Antipathies, hamnea warner, Trinidad
Botany Specimens: Ploeamium coccinea (Mrs Gray, October 1861)
Branching Form specimens from Fern Collections:
Gymnocarpium dryopteris, Blechnum spicaut, Polypodium, Roberiana beauv, Belchum spicant, Gluchuria dichotoma lilla, Thelyptisis robertiana slonon, Blectnum spicant.(Fig.A.3.1 and A.3.2)

Spherical form:
Mineral Specimens: Quartz: chalcedony (Oman), Psilomelane: Romania (1906, 249), Prehnite, Smithsonite
Zoology Specimens: Puffa/porcupine fish: diodon maculatus, diodon maculifer, Tetrodon palembangensis (siam), Tetrodon iagocephalus, Diodon maculatus (cape seas)
Botanical Specimens: Posidonia caulini, Arctium lappa, Allium carulam, Fagales, Quercus trunsata king, Castanopsis javasica (fagales 51).
Phallus Form:
Mineral Specimens: Goethite, Chalcedony, Psilmedare, Smithsonite, malachite, gyrolite, Barite
Botany Specimens: Dreanculis vulgaris, Vigelvein 820, Aconis calamari, Acoruscalalam

A.4: Examples of different Isomorphology workshops

A.4.1 Grant Museum Isomorphology Drawing Workshop: 21st March 2013, 7-9pm

A blogpost has been published about this workshop: 'Rearranging the Natural World' (Anderson, 2014) http://blogs.ucl.ac.uk/museums/2013/05/09/isomorphology/

This Isomorphology workshop aimed to introduce the forms and symmetries that can be observed and drawn from the Grant Museum Zoology Collection and UCL's Geology collection. This workshop coincided with the solo exhibition 'Isomorphology' (at Eb and Flow Gallery, 77 Leonard Street, London, EC2A 4QS). The exhibition ran between the 7th February until the 7th April (Tuesday-Friday 11am-6pm, Saturday 1-5pm).

Preparation:
Install Isomorphology etchings and symbols in cabinets
Museum Curator Dean borrows drawing boards
Set up etchings and Isomorphology publications alongside specimens for drawing
Organise loan of mineralogy specimens from Rock Room mineral collection, University College London (Fig.A.4.1.1-A.4.1.6).

An important part of the Grant Museum workshop was selecting specimens for participants to draw from. I selected the following specimens and temporarily re-ordered them within the museum for the duration of the workshop:

Bull shark's jaws: bilateral and three fold
'Ben the cobra' snake skin: spiral
Preserved brains: hyperbolic
Blaschka glass models: eight fold
Venus flower basket: spiral
Butterflies: bilateral
Salamander skull: bilateral
Hydrozoans: branching forms
Brain coral: hyperbolic
Spiral shell comb: spiral
Starfish: radial
Sea urchins: five fold
Annelids: bilateral
Crustaceans: spiral and bilateral
Scorpions: spiral
Spiders: eight fold
Bosc monitor: spiral and scale pattern
Fish models: bilateral
Porcupine fish: radial and spiral and triangular
Model of human heart compared to shell cross section (NHM drawer of cross sections)
Sectioned shark vertebrae: four fold (compare to andalusite mineral specimen at UCL)
Radiated tortoise shell: hexagonal
Fossil turtle shell scales: spiral (compare to pine cone)
Rue deer skull: spiral

Antlers: branching
Coral snake: spiral
Sea horse: spiral
Peacock feather, fern, fish scales, butterfly wing scales: spiral
Bat wings: three fold
Wasps/Bees: four fold

<u>UCL Rock room specimens for Isomorphology workshop</u>:
(Number of specimen and notation of its relation to Isomorphology)

9 and 26- crinoids
48- hexagonal
54- dendritic
53- fern branching
50- radial symmetry
70- spiral mollusk fossil
63- five fold echinoderm
79- hyperbolic like brain
85- fossil crab
120- haematite kidney-like specimen
11- four fold symmetry
41- leaf- like fractal fractal specimen
85- four fold
81- radial wavellite
69-aragonite branching
64- three fold tri-angular
127- chalcedony- bubbling
122- four fold
112- three fold
124- six fold

A.4.2: St.Ives Isomorphology workshop 11th May, St.Ives School of Painting 2015

I was invited to teach a three day workshop by Alison Sharkey, Director of the St.Ives School of Painting. The workshop was advertised through the school and was booked to full capacity. The three day workshop provided an opportunity for me to integrate Isomorphology, the Goethe drawing method and Isomorphogenesis into one workshop. The first of the three days was structured as an Isomorphology workshop based in the studio and the field.

The following is an extract from my Journal which records the nature of this three-day workshop:

10am - I introduce Isomorphology using artworks, publications and specimens loaned from Exeter University Zoology teaching collections which show examples of the forms and symmetries. I discuss resemblance as basis/principle for drawing relations between animal, mineral and vegetable.

We begin the workshop by 'tuning' our eye to observe some of the forms by looking at the Exeter zoology specimens in studio. I then introduce the concept of 'artistic fieldwork', using a diagram made on Scilly comparing artistic and scientific approaches to fieldwork. I ask the group to think about the questions we are bringing to the field; we have morphological questions, which are both questions of art and questions of science. We walk together to a site on the coast path which has an interesting diversity of plants. As we apply the forms and symmetries of Isomorphology to our observations in the field, it becomes apparent that individual plants are in fact communities of many of the forms and symmetries of Isomorphology - each body begins to reveal itself as yet another landscape of form[3]*. The time we spend observing rewards us, as a connected series of forms reveal themselves.*

At this point the translation between the two and three dimensional becomes significant. Isomorphology symbols are two dimensional and have been abstracted from the observation of three dimensional specimens. In our observations of the field and the museum specimen, we reverse this dynamic and project the two dimensional symbols on to three dimensional objects: plant, mineral or animal.

The first challenge in the field is trying to correspond the two dimensional abstract Isomorphology forms with the three dimensional plant individuals we encounter, each its own variation on the theme. Every individual is a three dimensional manifestation of one or more of the two dimensional abstract forms which can be clear or coded depending on the motivation and training of the individual observer. Observing in the field is both an act of interpretation and of translation. We 'find' the form amongst the many possible perspectives which either hide or reveal the forms of Isomorphology. This requires a conceptual flexibility of working between the 2-d and the 3-d.

We use the 2-d forms and symmetries as a guide to begin drawing, sketching the 'bauplan', and then furnish with idiosyncratic details of the individual, which are always a casualty of 'pure' form. The human mind, which naturally inclines towards symmetry, completes the imperfections of the reality we are presented with by projecting the abstract (Isomorphology

3 It quickly becomes apparent that each plant, animal or mineral form we look at is a composite of more than one of the forms of Isomorphology. Each 'individual' becomes a community of form species.

or other) form onto the observed reality to complete the picture. For example, we found a partially spiralling shell and we projected our own completion of the form to maintain/ substantiate the spiralling form that we want to know. The mind projects a version of the ideal spiral form onto nature's own incomplete reality.

In order to begin drawing, we need to choose one perspective, where we find one of many possible answers to our question 'what are the forms and symmetries of this animal, plant or mineral?' By selecting one perspective, we automatically de-select a thousand others, but this is a necessary commitment to begin drawing. Practiced observation increases our ability, considering the human as the instrument of perception, to 'tune in' to the forms of Isomorphology.

As we move to do fieldwork on the beach, we consider Isomorphology forms across a wide range of earth scales and times. We look at the geology on the beach and we see the weather revealed in its nature, then see the rock as a microcosm; stoma, branching seaweed - a landscape of form.

There is a natural order to our vision: first we see the Isomorphology forms of the whole – the macro, zoomed out view- and then we see the Isomorphology of the parts - the micro, zoomed in view - which contributes to the community of form in any individual.

First we see forms which are more obvious, like branching forms, followed by more subtle or complex forms, like the spiral arrangement of the inner flower. The perspective we chose opens up new possibilities, for example, we would see other things if we took cross sections of the stem and abstracted it to see a multi-sided prism, or if we abstract the rocks to see an isosceles triangle and expand this to see branches as isosceles equivalents, all individual variations on the theme.

Many Isomorphology forms remain invisible to the naked eye. To understand the relation of amorphous granite boulders to the forms and symmetries of Isomorphology, it is helpful to think of the seven crystal systems and imagine the formation of granite - a hybrid of quartz (hexagonal) and other crystal structures that somehow ends up with its weathered amorphous form.

Back in the studio, we reflect. In the field or the museum we do not see the whole image of the natural form that the scientific textbook presents us, often without imperfections. Rather, we see the non-whole/unholy, non-perfect, damaged and fragmented reality.
(Fig.A.4.2.1 and A.4.2.2)

<u>Afternoon:</u>
It is interesting to see how different individuals order specimens in different ways, there is first a selection of specimens in the field/museum and then further selection when choosing what

to draw. First there is a classification of collections in different ways beside the drawing plane (shells/plants/ animals…) and then another classification of collections within the drawing plane. Each collection and order is motivated by an enquiry into form and symmetry, which directs and determines the collection whilst still remaining open to chance.

Decision-making is happening consciously and unconsciously, first in the field or museum based on observed form and symmetry, and later in the studio or lab when decisions are ade about rotation and perspective to draw from and whether to draw parts of or the whole specimen. There is also the decision to zoom in or zoom out. Decisions revolve around selecting salient morphological features.

Using the two dimensional Isomorphology symbols as a bau-plan or guide to draw around is a helpful basis for drawing details of spiral/five fold/six fold etc. Then there are decisions of composition- decisions about where to begin the drawing, how it builds and where to end, these are largely intuitive decisions.

With a collection of specimens showing the forms and symmetries of Isomorphology alongside the page, it is helpful to then identify two or more specimens (possible to mix up specimens from field or museum) that share a form or resemble each other, for example: 2 branching forms and first imagine how to draw this relationship, which requires an act of visualization which can then be made visible through drawing. Through drawing, we physically realise morphological relationships in the space of the page, we explore relationships which have been discovered through this process and can be shared with others through drawing.

Drawing grants permission to zoom in and zoom out, allowing scale and function to become flexible/plastic in the space of drawing. A cross section of a stem can become the same scale as petals and suggest a new function through this new relation and positioning. Scale and function slip around, stems become promoted to sex organs when drawn as stamens.

When drawing we begin to build the form into our memory, which allows us to improvise with the form without looking at the specimen. The drawing process shifts from direct observation to improvising based on this observation- a liberation from observation. This improvisation runs throughout the creation of each Isomorphology etching (which is drawn directly onto the plate), it is both surprising, challenging and uncomfortable. As we improvise we feel inclined towards the abstract, we play with form as our thought also becomes abstract, and this thought becomes embedded in the drawing. (Summarized as: improvising based on what has been learnt in previous drawing, naturally start to draw without observation, improvising, inclined towards the abstract whilst maintaining observational elements).

The group start to draw based on the pattern, no longer from observation and freed from their habitual approach. Participants described this transition as liberating in the possibility to *create, but also uncomfortable, even 'scary' to use the imagination.*

I encourage participants to think about improvising through drawing as a kind of 'sampling' or re-mixing of natural form, recombining like DNA or re-composing like a DJ to create a new order for the parts. This new combination might create a new body or landscape of form.
(Fig.A.4.2.3-A.4.2.6)

A.4.3: Isomorphology workshop at the Eden Project 29th May, 2015, 11.30-3.30pm

I proposed an Isomorphology workshop to the Eden Project, who responded positively and invited me to create an Isomorphology workshop as part of 'Strange Science' week in May 2015. The following journal extract records and reflects on the workshop:

I decided to base the workshop in the Tropical Biome and to 'plant' Isomorphology forms and symmetries (as drawn on paper) alongside corresponding plant forms. I created a worksheet with a list of Isomorphology forms and symmetries that people could take around the Biome with them, like a treasure hunt. In the morning I selected plants from within the Biome that were good examples of the forms and symmetries of Isomorphology and I then placed these specimens in the 'Bam Bams' hut where I was based, alongside corresponding Isomorphology Symbols. This was a re-collection and re-curation of plants in the Tropical Biome based on the shared forms and symmetries- of Isomorphology. I also hung Isomorphology images and wooden shapes around the hut structure. When the workshop space was set up, I provided paper and pencils and guidance of how to draw plants in relation to Isomorphology and the public came into the workshop space for as long as they wanted and then left, which was a successful model for this context.
(Fig.A.4.3.1-A.4.3.10)

A.4.4: Isomorphology workshop at Tresco Abbey Gardens

An earlier Isomorphology workshop at Tresco Abbey Gardens, Isles of Scilly (14th October 2012) followed a similar structure but was based in the garden itself and a small workshop area (where I set up Isomorphology symbols in relation to plants collected with a gardener) rather than a Biome.
(Fig.A.4.4.1-A.4.4.7)

A.5: Images of compiling Isomorphology publications

(Fig.A.5.1-A.5.8) and link to photocopy publication pdf (Fig. A5. a,b,c and d))

A.6: Images of Exhibitions and Public Talks:

(Fig.A.6.1-A.6.10)

A.7: Reflections from a Scientist: 'Symmetry and Isomorphology' by NHM, Mineralogist, Peter Tandy

The natural world has a very symmetrical aspect to it. It isn't always obvious and because we live in it, we take it all for granted. But in the worlds of plants, animals and minerals, almost everything shows some form of symmetry. Much of this, especially in the animal kingdom, is two-fold, meaning that things are (broadly) mirror symmetrical. Cut them along this plane and then place one half against a plane mirror, and you restore the original animal. This is clearly evident in humans where we have two arms, two legs, two eyes, a central nose and mouth, etc., all spread equally across bisecting a mirror plane.

In the mineral kingdom, symmetry is more advanced due to the rigorous nature of the underlying structures, and combines more symmetry elements. This enables the kingdom to be classified in a mathematical way according the symmetry elements shown by compounds in their crystalline state.

In her work, Gemma has taken these elements of symmetry shown by members of all three kingdoms, and combined them in a new way to create artistic works, coming up with a new definition which she calls 'isomorphology' (literally meaning 'equal shape'). In this, various plants, animals and minerals, or parts of them, which show a similar shape and sometimes rotational symmetry, are juxta-positioned to create art works.

I have been working with Gemma for about 2 years, trying to supply mineral specimens which meet her criteria for symmetry groupings. Sometimes this has been reasonably straightforward, at other times it has been quite difficult and in a few cases, just about impossible. But where I was able to supply material, Gemma has used it in a clever way to create works which have a strange mystical quality about them. The works have something of an overall fairy-tale appearance, and yet on closer inspection, reveal items which are all individually real and recognisable, but placed in a world where they all come together in a dream-like setting. Each work is dictated by an underlying symmetry or isomorphology.

As a part-time artist myself, (who also draws/paints mineral specimens), I have been pleased to work with Gemma. Her requests for specimens have at times been taxing, making me think and look a bit laterally at examples of minerals, away from the more rigorous mathematical symmetry concepts I am used to. In this respect, Gemma has been good to work with, and I have enjoyed seeing her works as they progressed, occasionally offering some constructive criticism, though for the most part I can only offer praise. I was particularly pleased to be invited to take a small part in an exhibition she had in East Central London in 2013, showing some of my own mathematical polyhedra along with her own etchings and delightful glass knots.

> Overall, I am very pleased to have met and worked with Gemma, and believe that she may go on to have a great career in the arts. I wish her every success in the future. (Peter Tandy, 2014)

<u>A.8: ERICA Prototype Plant Identification Key including Isomorphology (by Colin French)</u>

This prototype plant identification key has been developed as a means of helping to identify wild flowers using a variety of simple flower and leaf characters. There are 3500 wild flowers in the underlying database. When trying to identify a plant specimen it only needs the selection of a few characters to reduce this number to a much more manageable list, from which a decision can be made as to the best match for the plant specimen.

Applying the principles of Isomorphology to flower symmetry has proven to be an effective means of classifying flowers without needing to know the constituent flower parts, such as the petals and sepals. The tulip, for example, has three petals and three sepals which look like petals. To the layman a tulip appears to have six petals. To simplify matters it has proven better to say the tulip has six-fold symmetry.
In the example below four-fold symmetry has been selected and the number of plant species has been reduced to 239.

Choosing yellow flowers reduces the number of plant species to 50 (fig.A.8.1).

Selecting rosette reduces the number of plant species to a more manageable 9 (fig.A.8.2).

Those plants can be viewed by clicking on the 'make selection' button. The nine plant species are then displayed as thumbnails. In this example eight drawings are displayed and one plant, which has no drawing or photograph, is represented by a block of granite (fig.A.8.3).

Clicking on the drawing displays it full size to help decide which of the nine plants matches the specimen to be identified (fig.A.8.4).

Clicking on the species name below the thumbnail brings up a screen showing the distribution of that wild flower in Cornwall, what has been written about it in various Floras, photographs of the flower and other resources.

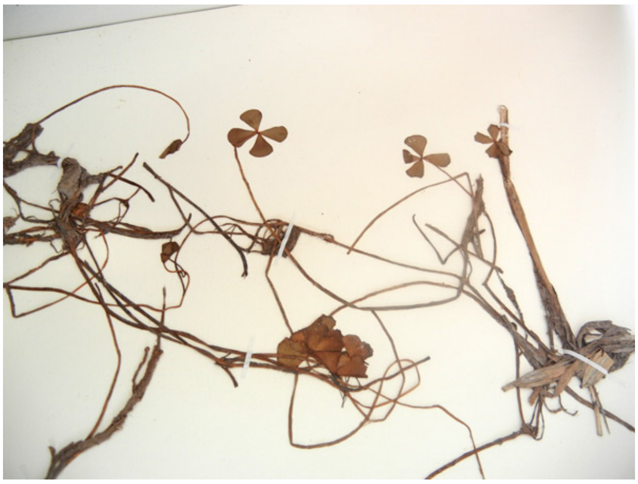
In this way several key presses reduce the number of possible matches for the plant specimen to be identified to just a few, which can then be individually viewed using drawings, photographs and other resources, and a decision can then be made whether there is a match for the specimen needing identification.

A.2.1. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.2. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.3. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.4. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.



A.2.5. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.6. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.7. ANDERSON, Gemma, 2014. NHM specimens showing four-fold symmetry. Photograph.

A.2.8. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.9. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.10. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.11. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.12. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.13. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.14. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.15. ANDERSON, Gemma, 2014. NHM specimens showing five-fold symmetry. Photograph.

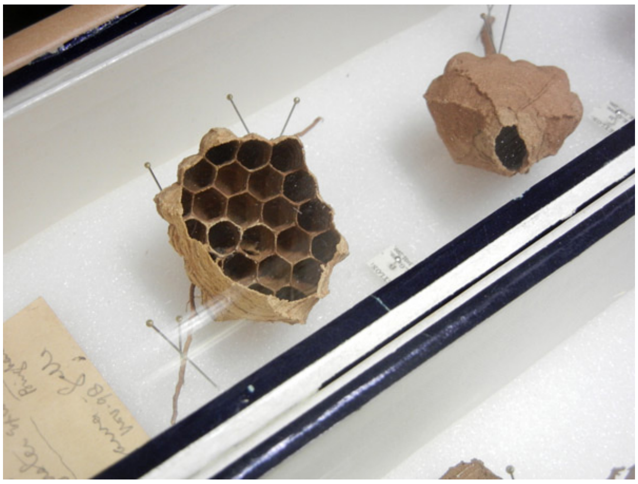
A.2.16. ANDERSON, Gemma, 2014. NHM specimens showing five-fold symmetry. Photograph.

A.2.17. ANDERSON, Gemma, 2014. NHM specimens showing five-fold symmetry. Photograph.

A.2.18. ANDERSON, Gemma, 2014. NHM specimens showing five-fold symmetry. Photograph.

A.2.19. ANDERSON, Gemma, 2014. NHM specimens showing five-fold symmetry. Photograph.

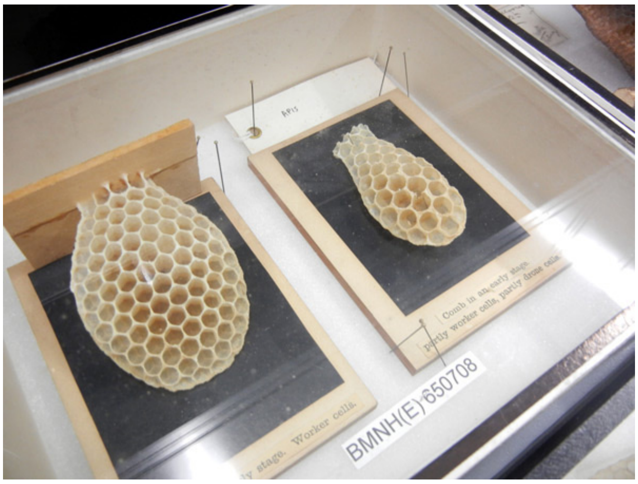
A.2.a. ANDERSON, Gemma, 2014. Insect NHM specimens resembling leaf form and showing bilateral symmetry. Photograph.



A.2.A. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry. Photograph.

A.2.c. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry. Photograph.

A.2.d. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry in Sackler Imaging LaA. Photograph.



A.2.e. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry. Photograph.

A.2.f. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry. Photograph.

A.2.g. ANDERSON, Gemma, 2014. NHM specimens showing hexagonal, six-fold symmetry. Photograph.

A.2.h. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.i. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.2.j. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms in the Sackler Imaging LaA. Photograph.

A.2.k. ANDERSON, Gemma, 2014. NHM specimens showing spiral forms. Photograph.

A.3.1. ANDERSON, Gemma, 2014. NHM fern specimens showing branching form. Photograph.

A.3.2. ANDERSON, Gemma, 2014. NHM fern specimens showing branching form. Photograph.

A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.

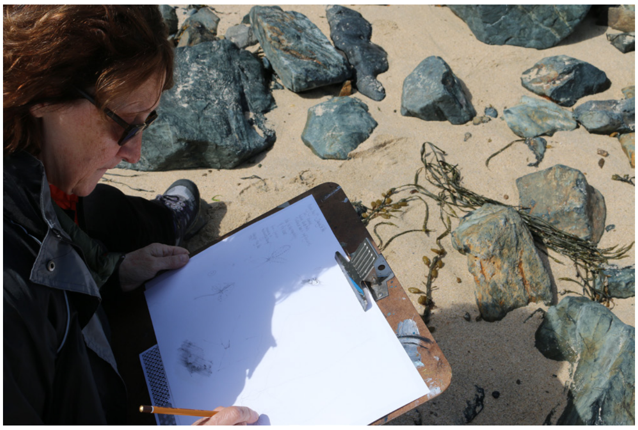
A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.

A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.

A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.

A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.

A.4.1.1-A.4.1.6. ANDERSON, Gemma, 2013. Grant Museum of Zoology Isomorphology workshop. Photograph.



A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.2.1-A.4.2.6. ANDERSON, Gemma, 2013. St.Ives School of Painting Isomorphology workshop. Photograph.

A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

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A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

A.4.3.1-A.4.3.10. ANDERSON, Gemma, 2013. Eden Project Isomorphology workshop. Photograph.

A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

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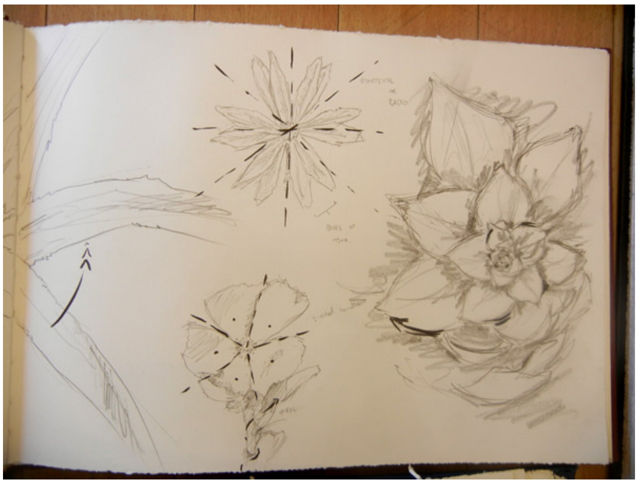
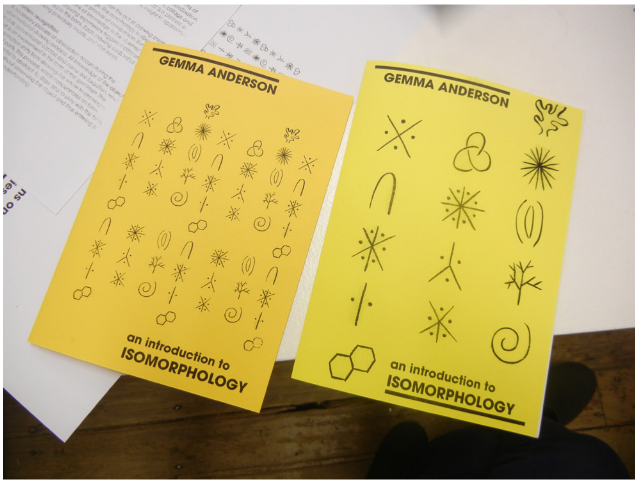


A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

A.4.4.1-A.4.4.7. ANDERSON, Gemma, 2013. Tresco Abbey Gardens Isomorphology workshop. Photograph.

A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

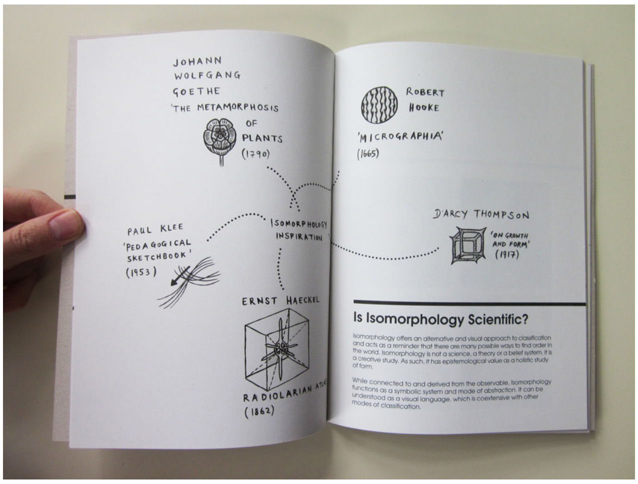


A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

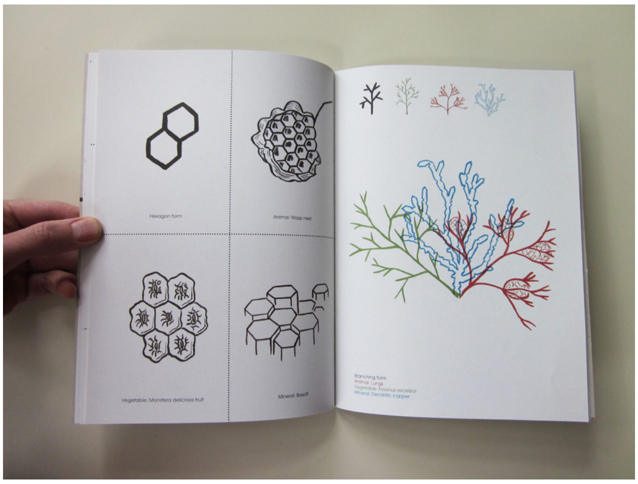
A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.



A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.



A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

A.5.1-A.5.9. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

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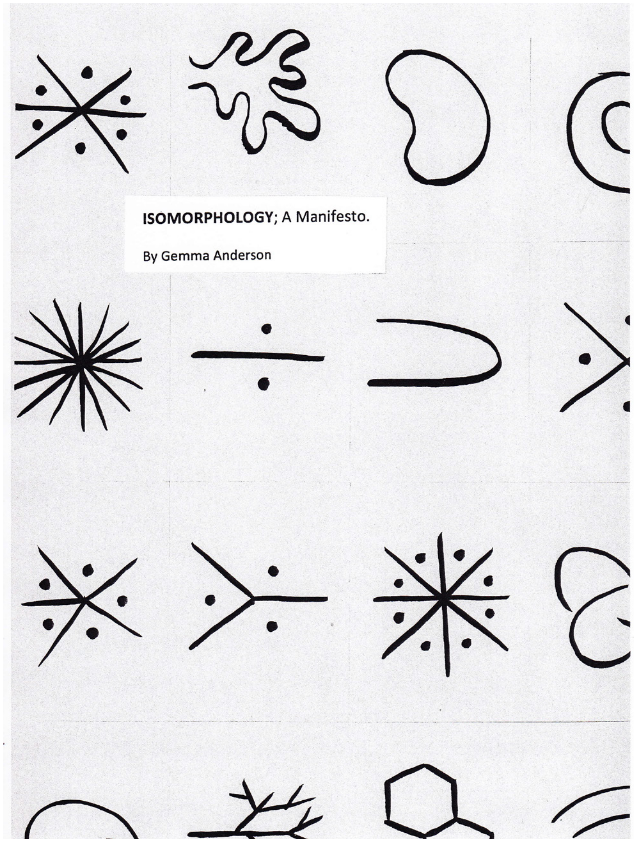
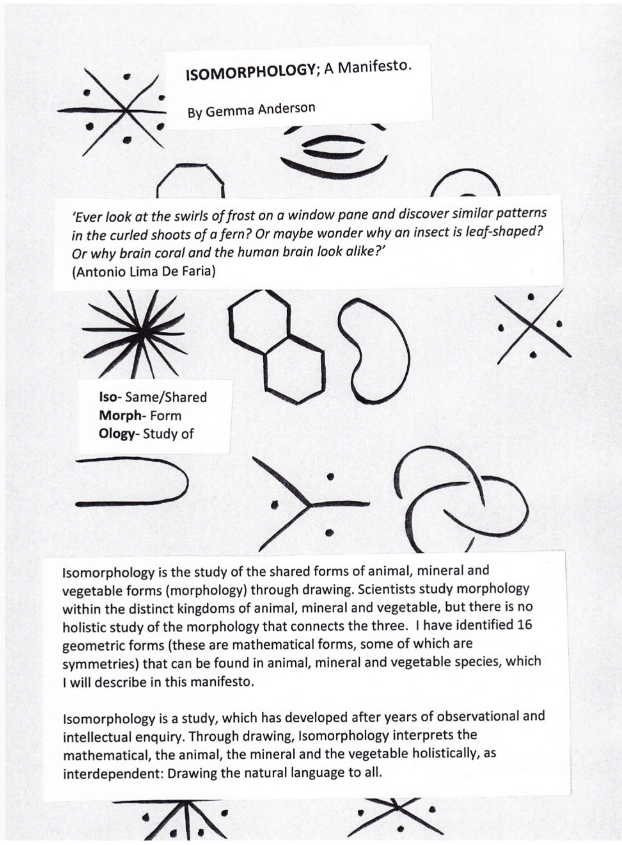
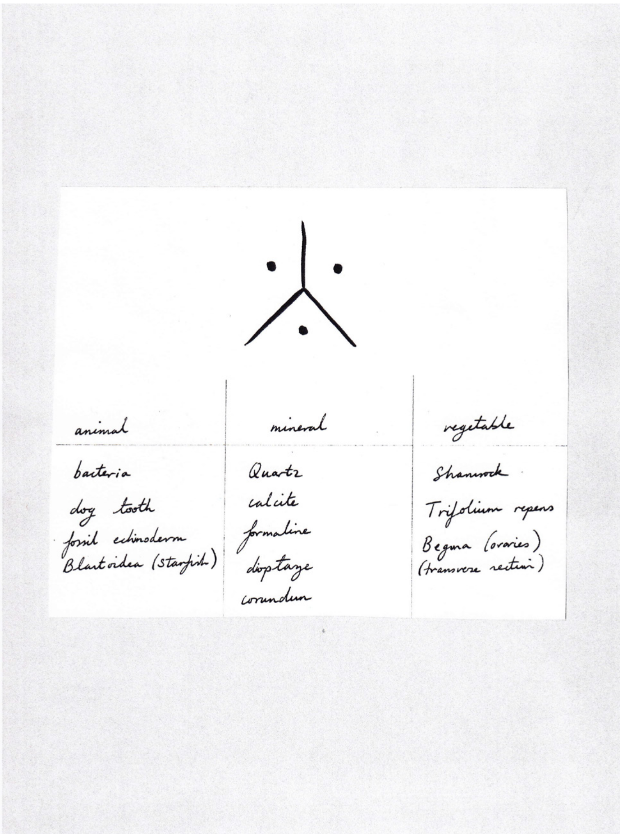


A.5.a. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.



A.5.b. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

A.5.c. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.



A.5.d. ANDERSON, Gemma, 2015. Images of Isomorphology Publications. Photograph.

A.6.1-A.6.3. ANDERSON, Gemma, 2013. Isomorphology exhibition, Eb and Flow Gallery, London. Photograph.

A.6.1-A.6.3. ANDERSON, Gemma, 2013. Isomorphology exhibition, Eb and Flow Gallery, London. Photograph.

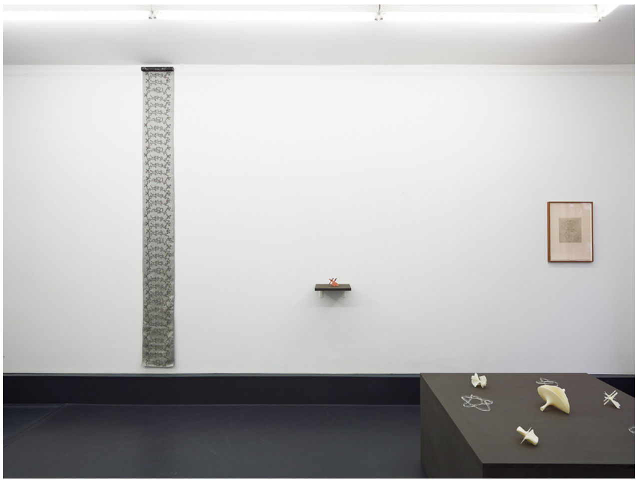
A.6.1-A.6.3. ANDERSON, Gemma, 2013. Isomorphology exhibition, Eb and Flow Gallery, London. Photograph.

A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.

A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.

A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.

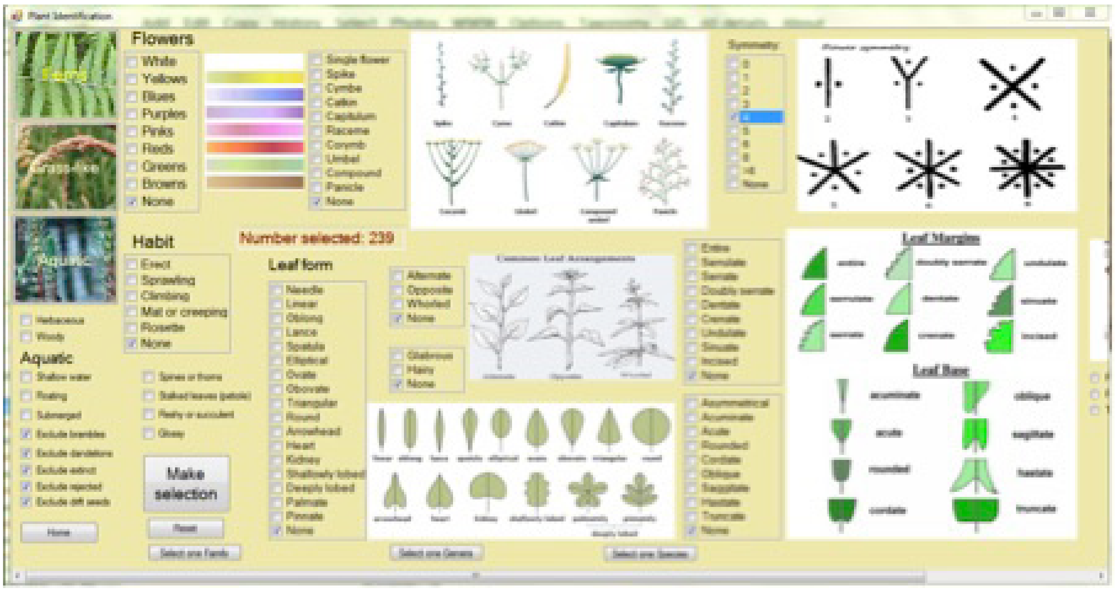
A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.



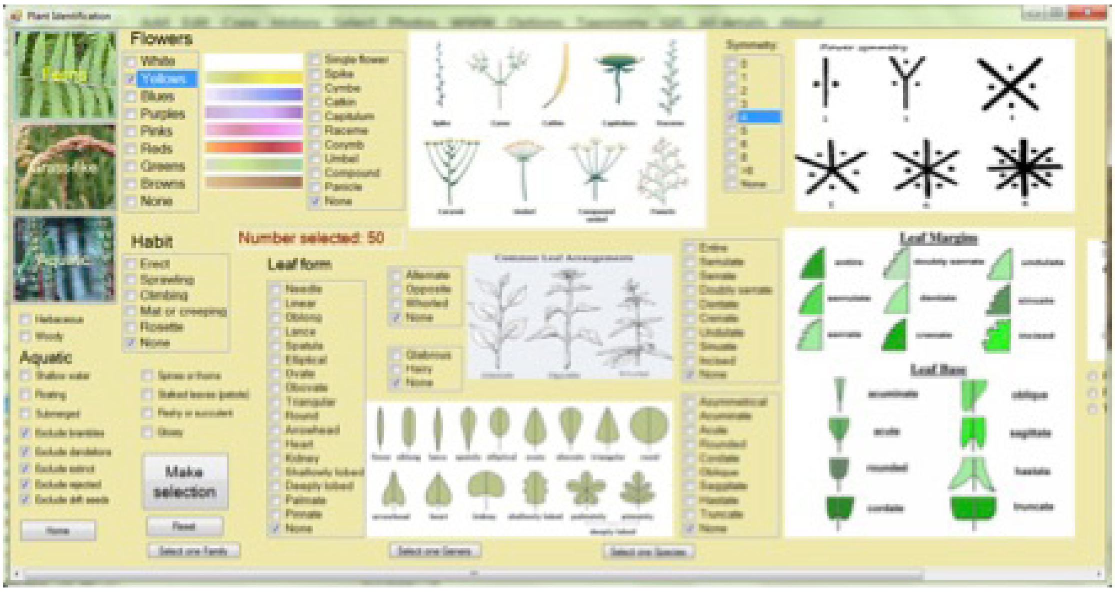
A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.

A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.

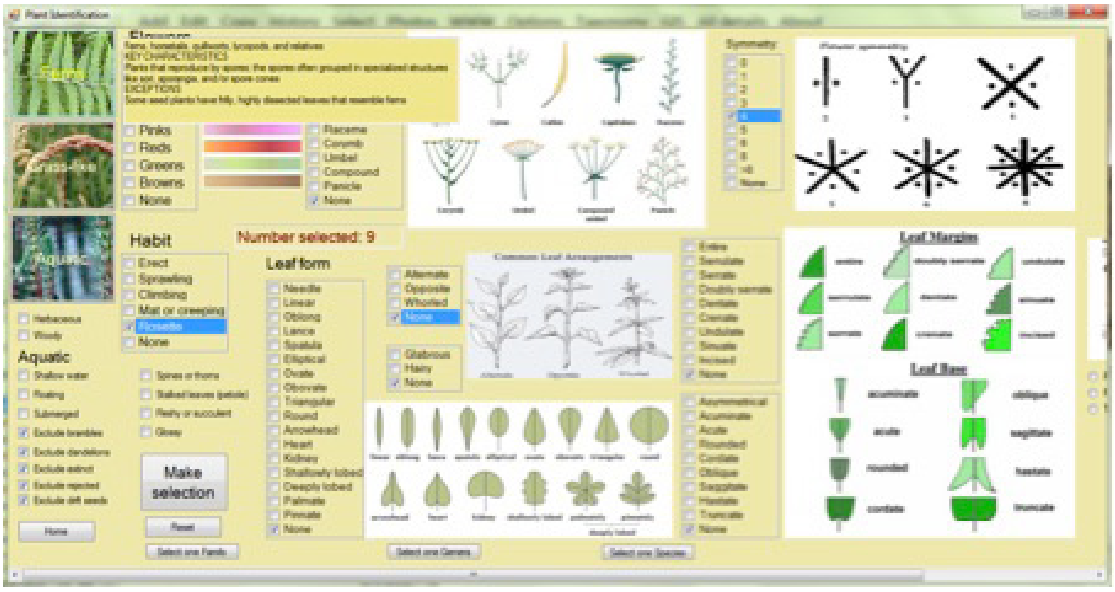
A.6.3-A.6.10. ANDERSON, Gemma, 2013. Isomorphology exhibition, Thore Krietmeyer Gallery, Berlin. Photograph.



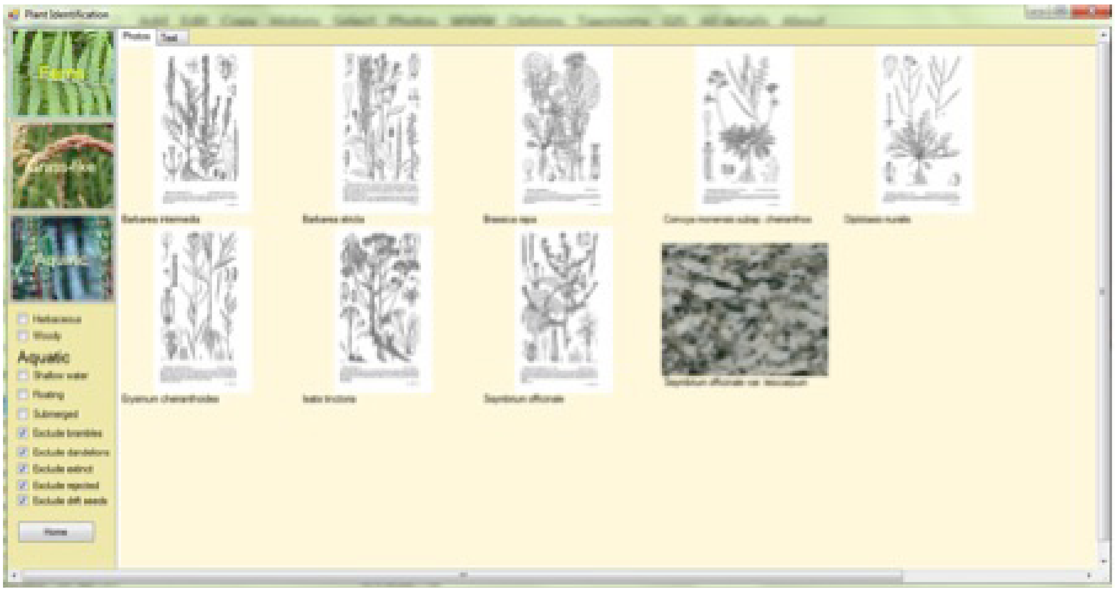
A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.



A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.

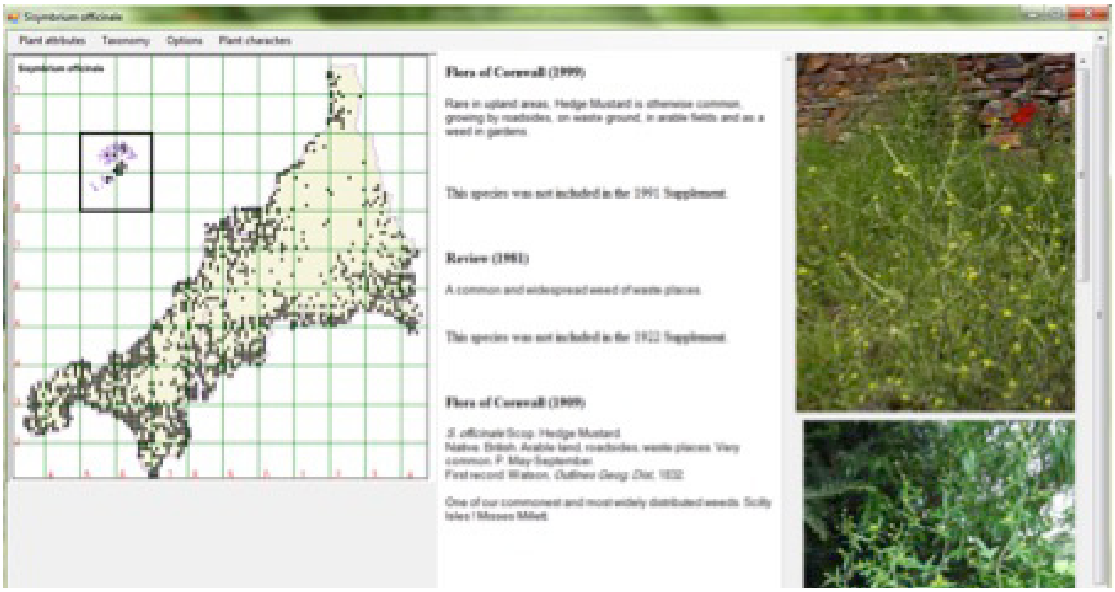


A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.



A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.

A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.



A.8.1-A.8.6. FRENCH, Colin 2015. Image of Isomorphology integrated into ERICA. Photograph.

A.8.7. MOORE, Rory, 2016.
Installation view of 'Drawn Investigations from Art and Science'. Photograph.

A.8.8. MOORE, Rory, 2016.
Installation view of Ulster Museum specimens correlating to Isomorphology symbols in 'Drawn Investigations from Art and Science'. Photograph.

A.8.9. MOORE, Rory, 2016.
Installation view of CMADC Web Archive in 'Drawn Investigations from Art and Science'.
Photograph.

A.8.10. MOORE, Rory, 2016.
Installation view of Ulster Museum specimens correlating to Isomorphology symbols in 'Drawn Investigations from Art and Science'.
Photograph.

A.8.11. MOORE, Rory, 2016.
Installation view of Ulster Museum specimens correlating to Isomorphology symbols in 'Drawn Investigations from Art and Science'.
Photograph.

Appendix B: Drawing with Goethe's Morphology – Workshops.

This appendix supports chapter five 'Drawing with Goethe's Morphology', with material about workshops which shared the Goethe inspired drawing method. The following sections are indicated at different points in chapter five.

B.1: Goethe Drawing Method Workshop Isles of Scilly
B.2: Goethe Drawing Workshop led in collaboration with Oliver Coleman at the Natural History Museum, Berlin
B.3: Adult Education workshop at Kestle Barton, Rural Centre for Contemporary Art, Cornwall
B.4: Workshop with BA Drawing and BSc Bioscience students at Exeter Bioscience Lab
B.5: Workshop as part of 'Across RCA' Royal College of Art Interdisciplinary Week
B.6: Workshop at the Drawing Room, London, as part of 'Drawing Making: Making Drawing'
B.7: Workshop at St Ives School of Painting

<u>B.1: Goethe Drawing Method Workshop Isles of Scilly</u>

August, 2013, 3pm-5pm.
A blogpost about this workshop was published on the NHM 'Nature Plus' website, see 'Art and Science on the Isles of Scilly' (Anderson, 2013a).

The following selected feedback from NHM scientists who took part reflects the nature of this workshop:

Erica (NHM Zoologist)
Which part of the method did you find the most enjoyable or interesting? Why?
Looking at the make up of the plant and noting/drawing how the parts go together- this went best.
Which part of the method did you find the most challenging? Why?
Drawing our own perceptions of the plant - it required you to know the plant quite well
Do you feel the method helped you to 'know' or think about the specimen in a new or different way? If so, could you try to describe this difference?
I had a better understanding of the make up of the plant and how the leaves attached to the stem
Do you feel that the method helped you to deepen your engagement with the specimen?
Yes- it was quite intense studying it for so long
Do you think this method could be useful in your scientific or artistic work? If so, how?
It was interesting to see how little I had observed the plant when it was taken away
Jasmin Perera (NHM Zoologist)

Which part of the method did you find the most enjoyable or interesting? Why?
I really enjoyed taking the specimen apart and really analysing the joints. It really made me appreciate the finest details.
Which part of the method did you find the most challenging? Why?
The most challenging part of the method was manipulating the specimen to create something new. After being in a mindset of stating things for what they are I found it a challenge to pass that barrier and change my train of thought. However, I was happy with the results.

Zoe (NHM Zoologist)
Which part of the method did you find the most enjoyable or interesting? Why?
Final section, combining the elements in an unexpected/imagined order.
Which part of the method did you find the most challenging? Why?
Drawing from memory – I wasn't expecting it and it was very revealing.
Do you feel that the method helped you to deepen your engagement with the specimen?
Yes – being asked to draw form memory made me realise there were aspects of the specimen I had over-looked, and which I then returned to and looked at properly.

B.2: Goethe Drawing Workshop led in collaboration with Oliver Coleman at the Natural History Museum, Berlin

This workshop explored observational drawing methods and techniques; introducing the Goethe drawing method to scientists at the NHM, Berlin. The reason for planning a workshop in Berlin was to explore how the method was received in a different cultural context and a scientific culture that is more familiar with the ideas of Goethe. The workshop was full of scientists and PhD students from the NHM, Berlin (30 in total). We drew from specimens from the NHM Berlin collections, it was a very large group and everyone was on time! Oliver Coleman (Zoologist, NHM, Berlin) talked about computer aided drawing techniques which posed questions about the different methods available to draw with today and allowed us to compare and contrast observational and digital drawing techniques.

Duration of workshop: The Workshop lasted approximately 2 hours.
Materials required: Pencil, Drawing Book (preferably hardback to lean on), any other drawing materials and camera optional.

Workshop Plan:
- Introduction of the workshop and the principles of drawing; methodology and technique. (It is advised to make notes).
- Show examples of drawings informed by the workshop method (directly observed from specimens).
- Outline of Method (7 Stages)

- Participants are then invited to follow the method with a specimen of their choice (specimens will be supplied, but please feel free to bring a specimen along if you wish)
- Group discussion of drawings and methodology, making sure the group understands the principles.
- Participants are then invited to continue drawing with particular emphasis on later stages of method.
- End; look at drawings and discuss possibilities of method and how it may be useful in scientific research.

All scientists engaged and made interesting work from the workshop apart from two who could not see the scientific point and gave up at the imagination stage - this was interesting as the reaction was more dramatic than in the UK where all scientists, baffled or not, were polite enough to follow the method to the end.

I also lead the same workshop model with scientists at the NHM London (Fig.B.2.1-B.2.5)

<u>B.3: Adult Education workshop at Kestle Barton, Rural Centre for Contemporary Art, Cornwall</u>

21st August, 2014

(Fig.B.3.1-Fig.B.3.4)
I was invited to give the Goethe method drawing workshop to an adult learning Ecology course from Camborne College. The workshop explored the method with a non-academic audience. The participants engaged with the method and produced interesting drawings. In a group discussion, we reflected on the difference between drawing from observation and drawing from memory.

The following is an excerpt from my journal notes about the workshop:

> Drawing from memory students tend to generalize form - they draw less individual variation between forms and tend to typify form more- for example - a flower that may have had petals more or less the same shape but which have dropped or curled in the time of drawing, or may have a snip or imperfection- an insect may have eaten part… etc… when drawn from memory the student tends to generalize the petals- making them more or less equal in shape and variation and posture… the student also frequently introduces rhythm into the lines that was not there in the original specimen… a bendy stem for example… this is an instinctive response to the plant and brings composition and balance/harmony to the drawing… when comparing observational and memory drawings these distinctions become clear…and the value of observation- the details of the observed drawing that do not stick in the memory because they are so nuanced- which are the very mark of the individual species in nature… are lost… this applies to all

scientific illustration which tends to generalize and to typify- this applies to our concept of the 'type'.

B.4: Workshop with BA Drawing and BSc Bioscience students at Exeter Bioscience Lab

January 2014 and January 2015

(Fig.B.4.1-B.4.3)
In this workshop, we practised the Goethe drawing method with Exeter Zoology specimens and laboratory microscopes. In this workshop I brought together a group of BA Drawing and BSc Bioscience students in Exeter Bioscience Laboratory so that we could explore artistic and scientific approaches to drawing and the students could have the unusual opportunity to collaborate as an Art/Science group. The following are examples of feedback from a Bioscience student and a Drawing student.

Feedback from Kate Buffery (Exeter Bioscience BSc student)
Which part of the method did you find the most enjoyable or interesting? Why?
Using the detailed observation of parts of the specimen to create larger pictures. It allowed detail and accuracy but also freedom to use your imagination.
Which part of the method did you find the most challenging? Why?
Drawing the specimen from memory, it really draws your attention to how much you are paying attention and retaining.
Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?
Your method really tunes you into the specific detail, which really tunes in the observation skills. As a science student, for identification of species you have to look for these kind of details, so it is good practise in observation.
Do you feel that the method helped you to deepen your engagement with the specimen?
I haven't paid so close attention to the specific morphology of a single specimen before.
Do you think this method could be useful in your artistic/ scientific work? If so, how?
When developing identification skills in species, knowing some of the morphological features needed to identify them would be very useful, so studying examples from different families of animals and plants could be very useful.
Any further comments?
It is great to think there is a place for drawing in science, and that applying drawing skills could help the scientific field.

Feedback from Minna Gawler-Wright (Drawing BA student, Falmouth University)
Which part of the method did you find the most enjoyable or interesting? Why?
I liked the drawing part! I liked being able to study specimens in detail; as I drew I had so many

questions in my head about them. By drawing them I felt I was able to understand them better and how they work, and how they fit in with the rest of nature. For me drawing is all about looking at relationships between things you can see; this workshop showed me the relationships between nature, the patterns, how things are constructed.

Which part of the method did you find the most challenging? Why?

Taking apart the specimen in my head and reassembling it on the page to make something else. I find it difficult to draw things in ways that I can't see. I did enjoy it though, it's just not my strong point.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?

I became more aware of the relationships between different species, and how certain patterns, shapes, and formations repeat themselves throughout nature. I really love this idea. With individual specimens, it was great to look at them in such close detail; something that would never be possible in the wild. With insects especially, it was great to study them to see how they were put together and similarities and differences between them.

Do you feel that the method helped you to deepen your engagement with the specimen?

Definitely. Being able to see nature this close up and study it for so long was great.

Do you think this method could be useful in your artistic/ scientific work? If so, how?

Yes, in so many ways. I think it's been useful to see potential patterns in nature that can be copied and used creatively. Also being given the chance to draw intricate detail and small things has made me realise I love creating fine detail.

Feedback from Hermione (Exeter Bioscience BSc student).

> I thought the most interesting part of the workshop was creating our own organism from studying the original in detail. I think it really showed how much more observant you can be than normal.
>
> The most challenging I feel was trying to dissect the specimen into small 'pieces'. I see the specimens so much as a whole organism that I found it hard to do this.
>
> I definitely think that I got to 'know the specimen better' from the workshop. It definitely helped me be more observant as a scientist and I think a lot of science based subjects don't put enough emphasis on how important observation is as a skill. I think that scientists really need to develop observational skills further as so much can be learnt from pure observation and once you have really studied a specimen, it is easier to see differences in other individuals.
>
> I think artists and scientists would benefit from working more closely together as the observational skills of the artist may benefit the scientist when looking at structure and morphology and science can just as easily be of benefit to the artist, for example I find it easier to draw something if I understand its form/have studied it closely.
>
> I really liked learning about the methods of drawing used and think there could have been more on this as I had never heard of it before. Also I think the workshop could have been

> longer, with more drawing time and perhaps getting a scientist to draw an outline of the specimen in a coloured pen then giving the drawing to an artist to draw an outline of the same specimen in a different colour to show the potential differences in observation. Overall I found the workshop really interesting and definitely think there should be more opportunities for this kind of thing in the future!

Hermione later wrote an article about the workshop for Exeter Bioscience student magazine 'Life' (Blomfield-Smith, H, 2014)

B.5: Workshop as part of 'Across RCA' Royal College of Art Interdisciplinary Week

Tuesday 29 October 2014, 10-4pm

(Fig.B.5.1-B.5.4)
I was invited by the Royal College of Art to deliver a one day workshop to an interdisciplinary group of RCA students with an interest in drawing. For this workshop, I organized to bring the group of RCA students to the Natural History Museum workshop space (at the Angela Marmot Centre) where we could draw from the NHM research collections. This workshop became a collaboration with NHM zoologist Gavin Broad who provided a tour of the collections and helped to source specimens for drawing. Gavin and I generated many points of discussion during the day based on our work together on the Isomorphology project. I began by introducing 'Isomorphology' and making connections between the natural sciences, mathematics, drawing and experimental methods. The following selected feedback from the workshop reflects the unique nature of the experience:

Alberto (Royal College of Art IDE MA student)
Which part of the method did you find the most enjoyable or interesting? Why?
I quite enjoyed the very first part, where we were writing down as much of the insect as possible. I've noticed this before in my practice, where I look at a certain piece of design and seems very simple at first. It's not only until I try to reproduce it that I realise how intricate and well thought-out it actually is. It's very easy for our -my?- eyes to cluster things in order to simplify them for a quicker assessment maybe? Anyway, really enjoyed letting myself take all the time I wanted in counting how many **x** the thing had. Kept thinking of Hunter Thompson typing out **The Great Gatsby** simply to experience what it felt like to write a great novel.
Did you like being at the NHM? If so, why?
The NHM is awesome! I've visited it at least a dozen times and it still manages to leave an impression on me. Who knew they keep such a huge data base of species... makes sense, but still.

Which part of the method did you find the most challenging? Why?
The most challenging/annoying was the first draft without looking at the specimen, nor seeing

the notes. This is specifically due to the fact that I'm completely useless at retaining instructions. It was not surprising -though frustrating- that I forgot to give it wings. grr!

Do you feel that the method helped you to deepen your engagement with the specimen?

It's key to mention that I would most likely have squish this insect when I saw one before this workshop. And so, being presented with this insect for whom a natural gradual sense of empathy (that only happens when constantly interacting with certain things e.g. ants) never existed, and then made to observe it, made me wonder how I would have reacted if, at 8 yrs. old, I would have been asked to do the same workshop. Would I still have gone and killed one? It's all about the empathy, hu?

Do you think this method could be useful in your creative work? If so, how?

Following a lecture touching on similar points by Peter Childs, I kept wondering on the small infinite possibilities, say for example, what the bio-engineering implications would be of putting grasshopper legs on it (what parts of its current anatomy would become irrelevant and obsolete?) and what would happen if you project this onto manmade objects? a lamp? a car? a coffee maker?

Would you like this RCA/NHM collaboration to occur on a regular basis?

yeah, as much collaboration with NHM as possible. I'm a firm believer that evolution has done most of the dirty work for designers and so the more we understand about these structures the better we can inform our pieces.

Harriet (Dyslexia tutor, RCA)

Which part of the method did you find the most enjoyable or interesting? Why?

1. The method was intriguing because when we started, we were not sure of where we would end - great. Also, because there were a series of exercises that made sense when looking back on them. Also, interesting to see what scientists might do a bit. Also, to deconstruct the observational drawings was very interesting and to start then being imaginative with micro parts was challenging and fun too. Endless patterns could be made. I particularly liked the idea of drawing from observation and then from memory - exciting.

Did you like being at the NHM? If so, why?

The activity was really interesting because of the setting, the specimens, your talk, the links to history/experts, and the tiny crossover with scientists! Good for all of us to get out of RCA for a while.

Which part of the method did you find the most challenging? Why?

Knowing and thinking in new ways - I think this always happens with drawing. Each time the focus and activity creates new perspective and insight into - in this case - amazing nature.

Do you feel the method helped you to 'know' or think about the specimen in a new or different way? If so, could you try to describe this difference?

Deepen engagement - certainly. I think this was palpable in the Darwin centre room as everyone was intent on the studies and so quiet and focused. Having the opportunity to work with such fascinating specimens was a part of this. Having the time was too. Each activity like that reminds us of the fact there is so much more to see and understand. And a world of possibility.

Do you feel that the method helped you to deepen your engagement with the specimen?

I would love to play with your ideas and practice more myself. Would love too to join in more workshops like this. (The students certainly did see the potential when they applied what they had learned to the children's workshop).

Further comments:

I think this would really work as a regular venture. Not just with RCA students but with schoolchildren, teenagers, adults, etB. etB. Getting into those scientists' corridors, cupboards, tanks, and drawers was brilliant.

Megumi: Royal College of Art Communications MA Student

Which part of the method did you find the most enjoyable or interesting? Why?

I found the stage which focused on one element of the specimen interesting. The process made me shift my focus from the general whole "shape" of the specimen but more on the finer elaborate "details" of the specimen which helped the drawing appear more sophisticated.

Did you like being at the NHM? If so, why?

Yes. Belonging to Visual Communication department surrounded by graphic design oriented people, I really forgot to relate to nature or science as research materials. I've learned that you can combine different areas of studies with art and expect the most interesting hybrid outcome from it.

Which part of the method did you find the most challenging? Why?

I found the last part where you asked us to go free challenging. It was only because I am from illustration and I am too much used to going free with drawings and I found myself being in my comfort zone at the last stage where I noticed my usual habit or my style of drawing getting in the way of myself reaching the new zone of drawing experience.

Do you feel the method helped you to 'know' or think about the specimen in a new or different way? If so, could you try to describe this difference?

I now know that many specimen can be related to each other when you observe well. Being an illustrator, I was trained to look at the general form of the object and draw the obvious shape leaving out the minor details for aesthetic reasons. But I discovered that actually any object is made up of countless microscopic elements which might be more interesting than its finished body.

Do you feel that the method helped you to deepen your engagement with the specimen?

Yes, I will now incorporate the method of first spending indulgent time in just looking at the object into my drawing routine. Being used to imaginative drawing, I neglected the importance of looking at real life objects then translating it on to a piece of paper.

Do you think this method could be useful in your creative work? If so, how?

Of course! I am now really interested in patterns that nature produced. There is something about organic forms that works well with drawing and I would like to expand this subject with my future projects using the method I learned.

If a follow up workshop could be programmed, how would you like it to develop what you learnt today?

If the illustration department was to have a workshop, I would suggest to skip the imaginative step of the method and train the illustrators to stick to some kind of systematic rule to get us out of our comfort zone. I would like to develop the magnifying step of the method to expand one element of the specimen into infinite possibility of pattern designs using method such as repetition.

Would you like this RCA/NHM collaboration to occur on a regular basis?

Yes. I think something really interesting and unexpected can come out of the fusion which will be beneficial for both parties.

Where do you think there could have been improvements in the workshop?

After I got a chance to see everyone's work, I thought that some students missed out on the fun by being too shy and rigid with the last creative drawing part. I think making people draw with their eyes closed or drawing with left-hand (right hand for left handed people) could loosen up the perception of "I need to draw something that looks nice" ideology. An environment to provide people with the feeling of back to being a child can be helpful by providing them with big sheets of paper not our standard boring A4 or instead of using designers 0.3 felt tip pens, painting with our hands and getting dirty.

Any further comments?

Overall I really had lots of fun and I could retrieve my child-like senses back from the workshop and got the grasp of losing control over my drawing and letting the process take over. Relating to organic forms helped my natural instincts to keep flowing. Thank you for the wonderful workshop Gemma! Great and very professional organisation too!

B.6: Workshop at the Drawing Room, London, as part of 'Drawing Making: Making Drawing'

22nd January 2014

Examples of participant Feedback:
(Fig.B.6.1-B.6.6)
This workshop followed the Goethe method, drawing from Natural History specimens but in the context of an art gallery where the exhibition 'Drawing Making: Making Drawing' included my Isomorphology etchings. Working in the context of an exhibition, where museum specimens were accessible for drawing, proved to be inspiring for participants. The following selected feedback reflects the unique nature of this workshop:

Florence Sweeney (BA Fine Art Graduate, Bournemouth School of Art)

Which part of the method did you find the most enjoyable or interesting? Why?

I found it most interesting when looking at the chosen object after drawing it from sight and memory, but then again in creating an abstract language. It was curious to speculate an object, for me barnacles on a shell, and visually breaking them down into a series of signs, of drawings. To focus on what the components are of what makes up the shell and barnacles itself.

Which part of the method did you find the most challenging? Why? (Please expand)

Drawing from memory I found most challenging, probably to resist the urge of looking which I found within myself that self control is the issue! But thankfully I managed to not have a look as having the written description about the item. By reading what I had descriptively written it brought back elements of what i have temporarily forgotten about the object, without that I would of found it far more challenging.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?

I felt by writing about the specimen it built up this connection of where all my attention was solely fixed onto it. I was paying attention to detail where if drawing the specimen, I could of potentially drawn what I 'know' which is a habit. But looking at every curve and crevice, i started to see the morphological components within its natural design. This method has taught me to look at objects or specimens in a more intricate way, instead of overlooking and taking it for granted.

Do you feel that the method helped you to deepen your engagement with the specimen?

Yes, in a way of building up an abstract language it was very useful. I also became quite fond of the specimen as felt like I was viewing it in a different way than if someone else was just to draw it from observation.

Do you think this method could be useful in your artistic work? If so, how?

Definitely so, if i next plan to do some drawings of any items or specimens i shall follow this method. It is feeding the eye and mind more knowledge and depicting parts of the specimen that i had overlooked. Also fully engaging with it, over the 4 process of drawing it. I plan to go to some locations to do site drawings (as live by the beach in Bournemouth) and shall adopt this method, it's quite poetic in a sense writing about it, then memorising it then drawing it abstractive. I feel this is how Old Masters would have approached drawing anything, really becoming involved with the subject matter. As teaching methods of drawing today have been dropped as seen of less importance, it's nice to become more in tune with the drawing.

If possible, could you reflect on the conceptual leap from observing, to abstracting, to recombining?

It felt natural from drawing the first two drawings of the specimen to exact or what the memory could remember, to then adopting the abstracting part of the drawing. It freed the mind in how to view it and that there is no right or wrong in how the drawing could develop, taking the specimen into my own personal view of what it could be in an abstract sense.

Was the background information and talk about Goethe and the Artist's method interesting? How was the delivery?

I found it highly interesting, so much so I have been researching further into the artists that were mentioned. Especially Goethe quotes - Knowing is not enough; we must apply. Willing is not enough; we must do. (Johann Wolfgang von Goethe). I feel looking at past artists quotes are motivational and also very helpful in broadening one's approach towards art.

If a follow up workshop could be programmed, how would you like it to develop what you learnt today?

I would like it to be on location, outside with all the elements to intertwine with what I would be drawing. Perhaps when drawing from memory it would change my perspective on the specimen, or landscape of foliage.

Any further comments?

I've planned to go to the Bournemouth Natural Science Museum and plan to carry on this method within my work, and also take it to the beach. Feel this method grounds my work when drawing as it's easy to become fed up with a drawing that doesn't represent what the specimen is or doesn't 'feel' right. With this method with the last two procedures there is no right and wrong but just the imagination of abstraction, which i loved. I thoroughly enjoyed the workshop and have decided to take on some of the methods within my own practice.

Otilia Heimat (Artist)

Which part of the method did you find the most enjoyable or interesting? Why?

Exploring the object step by step, and drawing the different patterns that could be detected, because it felt like an extension of looking and learning that went beyond just mere representation. A kind of meditation.

Which part of the method did you find the most challenging? Why? (Please expand)

Writing down the description. The language I know it is not enough to clearly name all that I saw.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?

Yes, it made me slow down and considerate the act of drawing in a more rounded way. That is i feel that I have appropriated so to speak the form. The two minutes observation + writing the description are key to this sense of 'appropriation' or internalization.

Do you feel that the method helped you to deepen your engagement with the specimen?

Absolutely.

Do you think this method could be useful in your artistic work? If so, how?

Yes. I am embarked in a long term project that involves drawing. As part of it, I use plant specimens. This method enhances the perception and understanding of the objects, thus helping to deepen my knowledge of them and the ability to generate better drawings.

If possible, could you reflect on the conceptual leap from observing, to abstracting, to recombining?

It is like getting to know somebody or something so well that you can recognized them just by a seeing them a tiny bit, since you have stored the information through the process.

Matthew Day (Artist)

Which part of the method did you find the most enjoyable or interesting? Why? (Please expand)

I enjoyed the abstraction and recombining process because it made me think in a different way and allowed me to make connections and observations which I would not of otherwise.

Which part of the method did you find the most challenging? Why? (Please expand)

Initially I would say the abstraction process, as I found it difficult to abstract my object in anything other than a generic way and difficult to develop a lexicon of marks. In retrospect I wish I had approached the mark making in a more creative way, as I think I used the pencil in a linear/ safe manner when trying to create form.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?

I believe that the method as a whole lead to a better understanding of the object as a 3 dimensional form as opposed to on object translated in 2 dimensions from a single viewpoint. The written description also allowed a development of the object as a starting point for the imagination through the use of analogy.

Do you feel that the method helped you to deepen your engagement with the specimen?

Yes, to an extent, I believe that my engagement and subsequent satisfaction with the process was in its ability to use a form as a starting point for further imaginative leaps rather than as way to know the object. I am unsure whether my satisfaction in where the process took me is the same as having a deeper engagement with the specimen - though maybe one would not of arisen without the other.

Do you think this method could be useful in your artistic work? If so, how?

Yes, as a starting point and process to develop work from the everyday.

If possible, could you reflect on the conceptual leap from observing, to abstracting, to recombining?

I think that the process allowed a systematic understanding of some of the concerns an artist has when making. I feel that the representational image created by observational drawing can be an exercise in skill and perseverance and not necessarily that creative. I felt that the workshop offered a window into the creative process of observation

Was the background information and talk about Goethe and the Artist's method interesting? How was the delivery?

This was interesting and well delivered, I liked the idea that the process formed conversations and possible discovery and that it linked the imaginative with the scientifiB. I feel that science can be viewed in rather unimaginative terms.

If a follow up workshop could be programmed, how would you like it to develop what you learnt today?

I think it would be interesting to further dialogue and conversation. I believe that the workshop showed a role for art outside of the decorative or descriptive and that a mixture of scientists and artists participating would offer interesting results in terms of dialogue and imagination.

Any further comments?

I really enjoyed the experience as I found that it lead to a deeper engagement with the artist's practise. Having received an undergraduate art education based on dialogue it was enjoyable to see the possibilities of engaging in a directed process; a doing and making leading to understanding. Thanks for the workshop I found it a really interesting and invigorating session.

Bartholomew Beal (Postgraduate Art student)

Which part of the method did you find the most enjoyable or interesting? Why? (Please expand)

Deconstructing the specimen and putting it back together into something new was really tapping into a really creative/artistic response to science, which also really helped me work out your method, and how striking the balance between art and science was so important(and so difficult!)

Which part of the method did you find the most challenging? Why? (Please expand)

As above, the most challenging was also the most engaging, as a sort of climax to the workshop, and each page around the room was coming up with such personalised drawing, so different to each other.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?....

For me, drawing is the best way to get to know something, and the focus required to draw something/someone really engages you with, the same applied to a very small butterfly, which had so much more detail than I have seen before.

Do you think this method could be useful in your artistic work? If so, how?

This will be a really useful addition to my range of painting tactics. Deconstructing an image and putting it back together into an undecided/abstract/unrecognisable form will be really entertaining when my figurative stuff is getting a little stagnant...

Was the background information and talk about Goethe and the Artist's method interesting? How was the delivery?

Really interesting/engaging delivery, with the images on screen vital. It really helped us all delve deeper into your work and where it all starts.

Ellie Watson (BA Fine Art graduate, Wimbledon College of Art, UAL, London)

Which part of the method did you find the most enjoyable or interesting? Why?

I really enjoyed re-drawing it by memory, it was like completing a satisfying puzzle.

Which part of the method did you find the most challenging? Why? (Please expand)

I really struggled with deconstructing the form into smaller units.

Do you feel the method helped you to 'know' the specimen in a new or different way? If so, could you try to describe the kind of knowledge that was generated?

I definitely feel like I 'know' my moth, I could re-draw it today and feel the same familiarity. I think there is also a natural kind of categorisation which is altered by this kind of method, which is very interesting. It's also interesting which elements I naturally chose to remember; it would naturally develop further if I were to continue with different specimens - like a pool of knowledge.

Do you feel that the method helped you to deepen your engagement with the specimen?

The structure meant that I spent much longer looking at the specimen. The words also cemented the understanding of the specimen differently, the recall is different.

Do you think this method could be useful in your artistic work? If so, how?

I think that I have gained a new way of thinking about observation, which can only be useful!

Was the background information and talk about Goethe and the Artist's method interesting? How was the delivery?

I found Goethe's theories really interesting, and I found it very engaging. It was definitely worth setting the theory before starting the drawing because it gave it context.

I think that it would be good to find a speedier way of getting through specimens so that the combination stage would have a bigger bank of shapes, but also might experience the recognition of those forms you were discussing at the beginning.

Any further comments?

It was brilliant!

B.7: Workshop at St Ives School of Painting

12th May 2015

I was invited to teach a three day workshop by Alison Sharkey, Director of the St.Ives School of Painting. The workshop was advertised through the school and was booked to full capacity. The three day workshop provided an opportunity for me to integrate Isomorphology, the Goethe drawing method and Isomorphogenesis into one workshop. The second of the three days was structured as a Goethe-inspired drawing workshop based in the studio. The Goethe-inspired drawing method facilitates a move from observation of the 'Isomorphology' of the whole organism towards an understanding of the Isomorphology of the 'parts' of the organism. This drawing process generates questions of form and function which Goethe suggested would naturally emerge from morphological study. The following extract from my journal records and reflects the nature of the workshop:

10am:

I begin with an introduction to Goethe as a polymath, who coined the term morphology in 1792, and give the example of his Metamorphosis of Plants- discovery 'all is leaf'- and use poems/quotes and drawings at this stage to give insight into his work. Goethe's few morphological drawings were not to make art but to generate and address morphological questions. We discuss Goethe's concept of 'delicate empiricism' and his proposition of the human as instrument.

The following is an excerpt from my journal about the Goethe method stages:
1. Begins- pure observing – no writing – no drawing- recall Isomorphology-forms study from yesterday- try to see for first time and forget assumptions- try to refrain from naming.
2. Writing about specimen- mix of poetic and scientific approach- using analogy , recall, metaphor and empirical/analytical description to build memory of the specimen- include notational drawing- identify Isomorphology forms. Option to rotate object/ describe form from multiple perspectives…this stage helps to challenge assumptions we tend to make/can make when we make quick observations. Some with scientific background find it difficult to move away from habitual approach- others use alliteration- poetic associations, resemblance, recall- 'a joy to see' questions about function emerge- 'how did nature do it?'
3. Drawing object in detail- informed by first two stages- zooming in and out of specimen- emphasis on drawing whole thing to build memory of relationship between parts and details of relationships- requires zooming in and zooming out.
4. Drawing from memory- generalize- compensate for imperfections- harder to intuit rhythm or easier depending on individual- much quicker because not back and forth between observation and the page- drawing from observation is drinking in the information and drawing from memory is pouring out… conceptual recall of zoom in and zoom out… Drawing from memory: difference between drawing – generalizing- making more symmetrical-
5. Drawing of parts- imagine specimen blowing up in space /expanding in space…zooming in- isolating parts- range of characters- like alphabet…- trend to make characters more 2 dimensional- flatten the pattern- but we are still working from a three dimensional body- (that is why helpful to then spend time drawing from Hepworth garden to think about parts of forms- abstractions as 3-d objects)
6. Recombining/reconstructing parts- surprising the possible organisms that evolve through this stage- bodies / beings that look like they could exist in the future, they may have existed in the past or a strange mutation of something we know. The joy of creating something new- of exercising the imagination.

Following the Goethe drawing method practiced in the studio, we transfer our understanding of form - gained from observing the natural world - to the artwork of Hepworth, in the Hepworth Sculpture Garden. St.Ives. I walk around each participant and offer some quotations from Hepworth which relate to Goethe's method while they draw:

> In the contemplation of Nature we are perpetually renewed, our sense of mystery and our imagination is kept alive, and rightly understood, it gives us the power to project into a plastic medium some universal or abstract vision of beauty (Hepworth, Tate).
> There are fundamental shapes which speak at all times and periods in the language of sculpture (Hepworth, Tate).

I think that the very nature of art is affirmative, and in being so reflects the laws, and the evolution of the universe – both in the power and rhythm of growth and structure… (Hepworth, Tate).

It is difficult to describe in words the meaning of forms because it is precisely this emotion which is conveyed by sculpture alone (Hepworth, Tate).

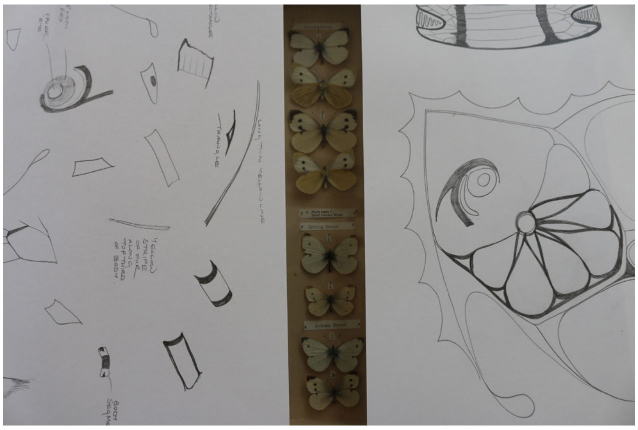
The predisposition to carve is not enough there must be a positive living and loving towards an ideal. The understanding of form and colour in the abstract is an essential of carving or painting; but it is not simply the desire to avoid naturalism in the carving that leads to an abstract work. I feel that the conception itself, the quality of thought that is embedded, must be abstract… (Hepworth, Tate).

We use our understanding of natural form to enhance our understanding of art forms and vice versa (Hepworth, Tate).

B.1.a. and B.1.b. ANDERSON, Gemma, 2014. Particpant drawing. Goethe drawing workshop at the Drawing Room, London. Photograph.

B.1.a. and B.1.b. ANDERSON, Gemma, 2014. Particpant drawing. Goethe drawing workshop at the Drawing Room, London. Photograph

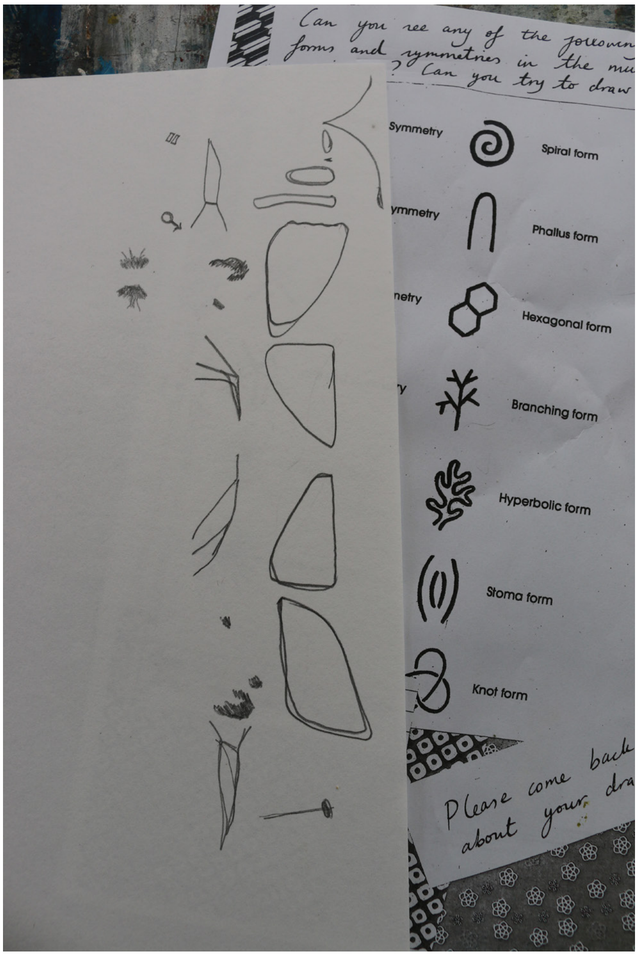
B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Goethe drawing workshop at St.Ives School of Painting. Photograph.



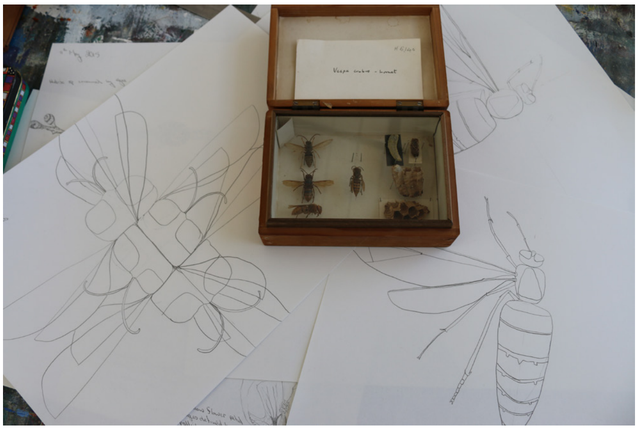
B.1.1 - B.1.10 ANDERSON, Gemma, 2015.
Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

B.1.1 - B.1.10 ANDERSON, Gemma, 2015.
Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

B.1.1 - B.1.10 ANDERSON, Gemma, 2015.
Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

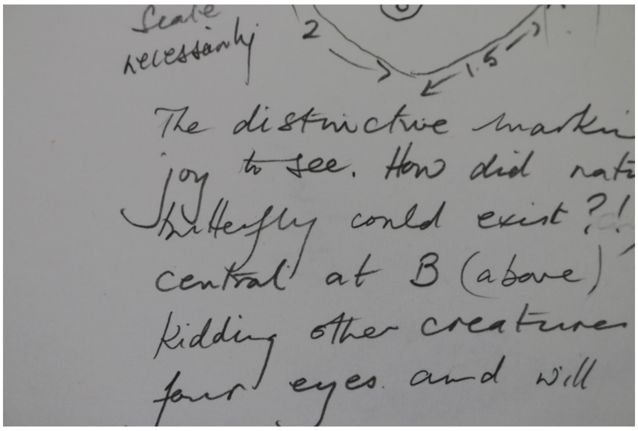


B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

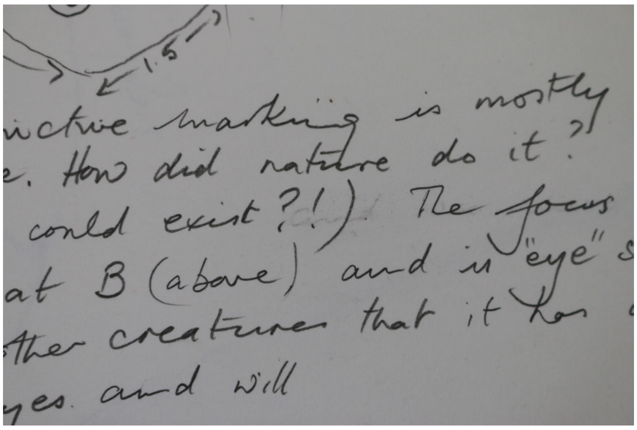


B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

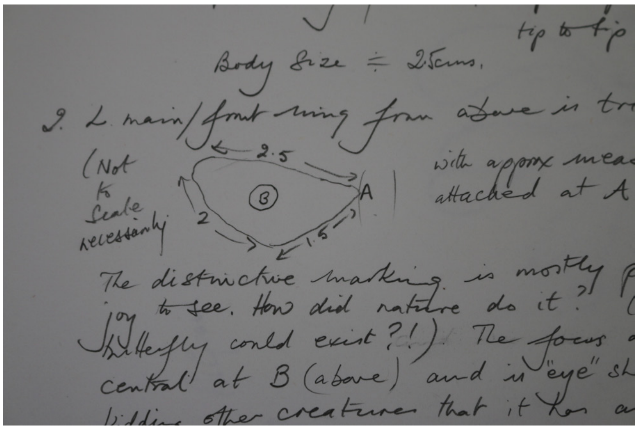
B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.



B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.



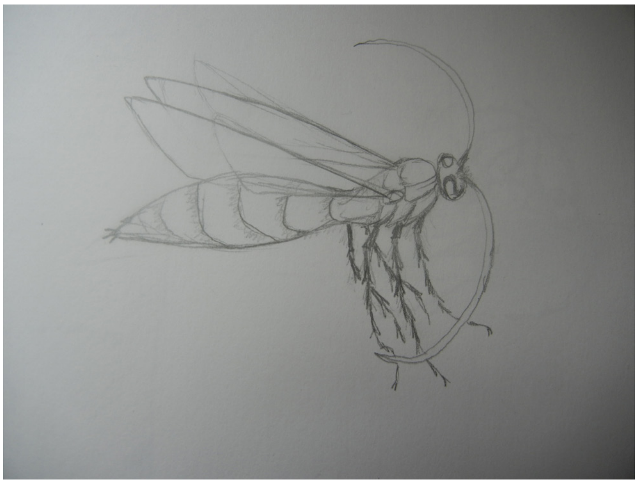
B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.



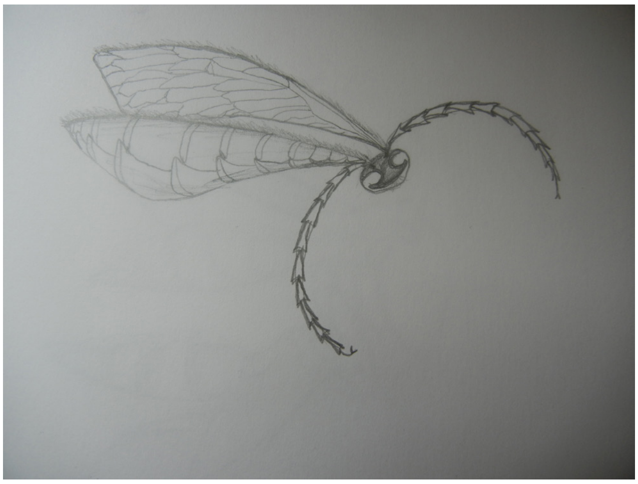
B.1.1 - B.1.10 ANDERSON, Gemma, 2015. Particpant drawing. Goethe drawing workshop at St.Ives School of Painting. Photograph.

B.2.1 - B.2.5. ANDERSON, Gemma, 2013. Goethe drawing workshop and NHM scientists drawings at the Natural History Museum, London. Photograph.

B.2.1 - B.2.5. ANDERSON, Gemma, 2013. Goethe drawing workshop and NHM scientists drawings at the Natural History Museum, London. Photograph.



B.2.1 - B.2.5. ANDERSON, Gemma, 2013. Goethe drawing workshop and NHM scientists drawings at the Natural History Museum, London. Photograph.

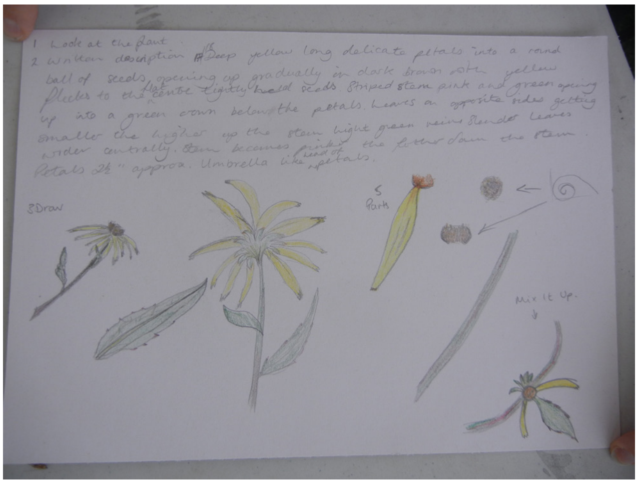


B.2.1 - B.2.5. ANDERSON, Gemma, 2013. Goethe drawing workshop and NHM scientists drawings at the Natural History Museum, London. Photograph.

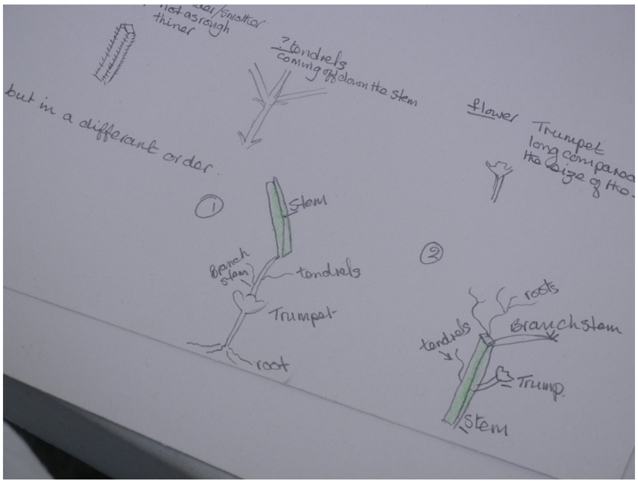
B.2.1 - B.2.5. ANDERSON, Gemma, 2013. Goethe drawing workshop and NHM scientists drawings at the Natural History Museum, London. Photograph.

B.3.1- B.3.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at Kestle Barton, Cornwall. Photograph.

B.3.1- B.3.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at Kestle Barton, Cornwall. Photograph.



B.3.1- B.3.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at Kestle Barton, Cornwall. Photograph.



B.3.1- B.3.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at Kestle Barton, Cornwall. Photograph.

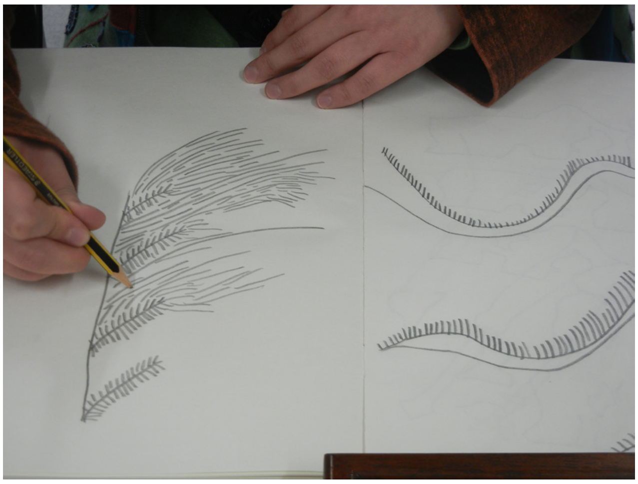
B.4.1 - B.4.3. ANDERSON, Gemma, 2013. Goethe drawing workshop and BA Drawing students at Exeter University Bioscience Lab. Photograph.

B.4.1 - B.4.3. ANDERSON, Gemma, 2013. Goethe drawing workshop and BA Drawing students at Exeter University Bioscience Lab. Photograph.

B.4.1 - B.4.3. ANDERSON, Gemma, 2013. Goethe drawing workshop and BA Drawing students at Exeter University Bioscience Lab. Photograph.

B.5.1 - B.5.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and Royal College of Art student drawings at the Natural History Museum, London. Photograph.

B.5.1 - B.5.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and Royal College of Art student drawings at the Natural History Museum, London. Photograph.



B.5.1 - B.5.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and Royal College of Art student drawings at the Natural History Museum, London. Photograph.

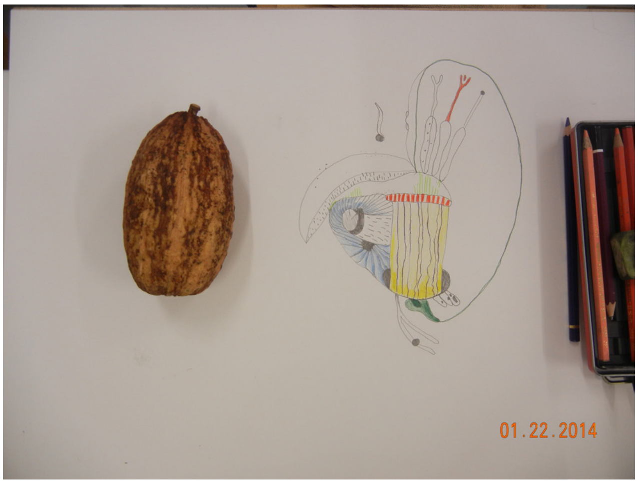
B.5.1 - B.5.4. ANDERSON, Gemma, 2014. Goethe drawing workshop and Royal College of Art student drawings at the Natural History Museum, London. Photograph.

B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.

B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.

B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.

B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.



B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.

B.6.1-B.6.10 ANDERSON, Gemma, 2014. Goethe drawing workshop and participant drawings at the Drawing Room, London. Photograph.

Appendix C: Isomorphogenesis drawing experiments and workshops.

This appendix supports chapter eight 'Isomorphogenesis: Drawing a dynamic morphology', with material about the Isomorphogenesis practice and process, workshops and exhibitions. The following sections are indicated at different points in chapter eight.

C.1: Isomorphogenesis Practice: Details of Experimentation
C.1.1: Actions inspired by Thompson's grid transformations
C.1.2: Details of Actions derived from studying images of cell development and direct observation or 'reading' of the growth of plants
C.2: Details of primitive forms of Isomorphogenesis
C.3: Isomorphogenesis Workshop at the Natural History Museum as part of the 'BIG DRAW' 2014
C.3.1: Isomorphogenesis drawing workshop with BA Drawing students at Falmouth University
C.3.2: Isomorphogenesis Drawing Workshop at St.Ives School of Painting
C.3.3: Second Isomorphogenesis Drawing Workshop at St.Ives School of Painting
C.4: Klee colour gradation method
C.5: Blue and yellow rules
C.6: Exhibition documentation and Process Biology publication images

<u>C.1: Isomorphogenesis Practice: Details of Experimentation</u>

This section provides details of individual actions performed in the artworks Isomorphogenesis four-fourteen. Each work was created in one day.

The following notes are transcripts which provide additional insight into the work (this is not necessary to view the works but it's available if more insight is required) were written directly after practice as a form of notation to 'read' the artworks. This text is in notational rather than narrative form – a kind of de-coding – as this is how I recorded the process during each experiment. The purpose of these notes is to provide a record of correspondence between the drawing action (verb) and the artwork.
(Fig. C.1.1-C.1.9)

<u>Isomorphogenesis no.1</u>
02-06-14:
I decide to begin with three columns which I evolve simultaneously.

Left column:
This series of form change is made following the formsynth drawing system. I start on the left with a sphere primitive and apply the following drawing actions to the form: multiply+rod, scoop, vertical shoot, merge, twist, tendril extend-divide, bulge+expand, crimp walls, beak, divide, add nucleus, change topology, branch, pod, add hairs (END).

Middle column:
This series of form change was drawn following drawing actions derived from the observation of cell development. I start in the middle with a sphere primitive and apply the following drawing actions to the form: add nucleus, dent, start divide, partial divide, contact divide, contact divide, double, multiply times two, partial separation, double up, multiply times two, segment into circle form, tendril extend, add segment, create inner circle, add self-similar parts, fractalize, merge, begin divide-upward side, thicken walls, add inner nucleus, add hair, spines (END).

Right Column:
This series of form change was drawn by mixing the approach of the formsynth drawing system and actions derived from the observation of cell development – mixing the approaches taken in the left and middle columns.I start in the middle with a hexagonal prism as primitive and apply the following drawing actions to the form: begin downward divide, further divide, add nucleus, contact divide, divide again, multiply, inner circle, double up, circulate, add segments, add tendril extend, crimp walls, de-segment, merge, divide (END).

<u>Isomorphogenesis no.2</u>
03-06-14:
I decide to evolve primitive form using my own 'Isomorphogenesis' adaptation of Latham's form synth system, which includes elements from D'Arcy Thompson's grid transformations, actions derived from the observation of cell division and elements from Thomas+Reif's 'Skeleton Space' and George McGhee's Theoretical Morphology.

Left Column:
I start the left column with a dodecahedron as primitive and apply the following drawing actions to the form: bulge, button symmetry, scoop, grid, add lateral shoot, subtract from another primitive, add smaller self-similar parts, fractalize, contact divide, double, thicken walls, apply grid transformation (oblique) (END). I then apply Paul Klee's colour gradation method in seven steps from warm red to pale blue and vice versa.

Right Column:
I start the right column with a pyramid as primitive and apply the following drawing actions to the form: multiply, apply grid transformation (oblique), add nucleus, twist, bulge, branch: 2,3,4, create inner circle (END).

Descendent:
I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): branching, multiply, angles, negative space, subtraction, doubling, contact divide, colour (END). I then apply elements of the colour gradation method from both adults.

Isomorphogenesis no.3

04-06-14:

I decide to evolve other primitive forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:

I start the left column with an icosahedron as primitive and apply the following drawing actions to the form: bulge, narrow, add nucleus, add angles, slice, thicken walls, multiply, top slice, scoop, change topology, apply grid transformation (oblique), thin walls (undo-reverse thicken walls), double, multiply x two, begin divide, divide, de-angle, bend, add vertical shoot (END). I then apply Paul Klee's colour gradation method in thirteen stages of yellow in and out of intensity (intense at stage 4,7 and 10) fading out and between at other stages.

Right Column:

I start the right column with a cube as primitive and apply the following drawing actions to the form: multiply, begin divide, partial divide, add vertical shoot, twist, narrow, elongate (END). I then apply Paul Klee's colour gradation method in six stages of purple.

Descendent:

I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): twist, divide, lateral shoot, scoop, nucleus. I then apply elements of the colour gradation method from both adults.

Isomorphogenesis no.4

27 and 28/06/14:

This was the first work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014. I decide to evolve other primitive forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:

I start the left column with a cylinder as primitive (as selected from hat) and apply the following drawing actions to the form: button symmetry-3 fold, twist, multiply, bend, slice, thicken walls, add vertical shoot, scoop, change topology, add helix to shoot, abandon bottom slice, drift top slices, add space between, segment, add symmetry-5 fold, (END). I then apply Paul Klee's colour gradation method in 11 stages from green to yellow.

Right Column:

I start the right column with a sprial as primitive (as selected from hat) and apply the following drawing actions to the form: add nucleus, beak, add spiral tongue, tendril extend, crimp walls, segment, divide (END). I then apply Paul Klee's colour gradation method in five stages from pink to yellow.

Descendent one:
I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): segment, helix, tendril extend, spiral, scoop, topology. I then apply elements of the colour gradation method from both adults.

Descendent two:
I decide to 'marry' the final (adult) form of the left and right columns together for a second time. I aim to maintain qualities from both adult forms,but different to the first 'marriage' and do this by using the following drawing actions (also used in 'adult' form): symmetry-5 fold, segment, spiral, segment, divide. I then apply elements of the colour gradation method from both adults (pink- green).

<u>Isomorphogenesis no.5</u>
29-06-14:
This was the second work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014.
I decide to evolve other primitive forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:
I start the left column with a pyramid (as selected from hat) as primitive and apply the following drawing actions to the form: stretch, de-angle, curve, crimp walls, add horizontal shoot, spiral, change topology, multiply (END). I then apply Paul Klee's colour gradation method in eight stages from blue to grey to pale blue.

Right Column:
I start the right column with a sphere (as selected from hat) as primitive and apply the following drawing actions to the form: partial divide, downward dent, divide, bend, add growth pod, add primitive: sphere, change topology, add beak, add observational element, double, partial divide, apply grid transformation (oblique), rotate, minus other half (END). I then apply Paul Klee's colour gradation method in nine stages from ochre and brown/green to light green.

Descendent one:
I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): crimp walls, topology, lateral shoot, observational element. I then apply elements of the colour gradation method from both adults (green/blue colour gradation)

Descendent two:
I decide to 'marry' the final (adult) form of the left and right columns together for a second

time. I aim to maintain qualities from both adult forms but different to the first 'marriage' and do this by using the following drawing actions (also used in 'adult' form): crimp walls, topology, observational element, spiral, lateral shoot. I then apply elements of the colour gradation method from both adults.

<u>Isomorphogenesis no.6</u>

30-06-14:

This was the third work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014.

I decide to evolve other primitive forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:

I start the left column with a octahedron (as selected from hat) as primitive and apply the following drawing actions to the form: scoop, add nucleus, slice, add angle, tendril extend, change topology, rotate, multiply (END). I then apply Paul Klee's colour gradation method in seven stages from dark grey to green to pale grey.

Right Column:

I start the right column with a hexagonal prism (as selected from hat) as primitive and apply the following drawing actions to the form: change topology, multiply x two, add observational element, bulge, de-angle, add nucleus, apply grid transformation (oblique), multiply x two, twist, begin divide, divide, apply grid transformation (oblique) left, narrow, elongate tips (END). I then apply Paul Klee's colour gradation method in nine stages from green to acid green to lemon.

Descendent one (left):

I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): divide, elongate, slice, nucleus, scoop, tendril extend, add angle (END). I then apply elements of the colour influenced by Cill Rialaig landscape: purple , green , grey and brown.

Descendent two (right):

I decide to 'marry' the final (adult) form of the left and right columns together for a second time. I aim to maintain qualities from both adult forms but different to the first 'marriage' and do this by using the following drawing actions (also used in 'adult' form): topology, angle, nucleus, tendril extend, slice, observational element, scoop, bulge (END). I then apply elements of the colour gradation method from both adults.

Descendent three (top right):

I decide to 'marry' the final (adult) form of the left and right columns together for a third time. I aim to maintain qualities from both adult forms but different to the first and second 'marriage' and do this by using the following drawing actions (also used in 'adult' form): slice, scoop, topology, divide, angle, observational element (END). I then apply elements of the colour gradation method from both adults.

<u>Isomorphogenesis no.7</u>

01/07/14:

This was the fourth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014.

I decide to evolve two forms, 'marry' the 'adult' forms to create descendents and then evolve descendent forms in two different directions and then marry the 'adult' forms of these lineages again using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:

I start the left column with a hexagonal prism (as selected from hat) as primitive and apply the following drawing actions to the form: add symmetry-5 fold, elongate, branch, bifurcate, marry (END). I then apply Paul Klee's colour gradation method in four stages from red to yellow.

Right Column:

I start the right column with a pyramid (as selected from hat) as primitive and apply the following drawing actions to the form: change topology, stretch, add symmetry, add arms (3), multiply, marry form (END). I then apply Paul Klee's colour gradation method from blue to purple in five stages.

Descendent one:

I decide to 'marry' the final (adult) form of the left and right columns together. I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): change topology, bifurcate, symmetry-5 fold, scoop (END). Form evolves in 2 directions from this descendent.

Descendent two:

I aim to maintain qualities from both adult forms, and do this by using the following drawing actions (also used in 'adult' form): beak, twist, bend, add observational element, bulge, change topology, stretch, bulge. I then apply Paul Klee's colour gradation method from pale blue purple green gradation.

Descendent three (right):

I aim to maintain qualities from both adult forms but different to the first and second 'marriage' and do this by using the following drawing actions (also used in 'adult' form): bulge and change topology, slice and lateral shoot/ marry (END). I then apply elements of the colour gradation method from pink to red.

Descendent four (left):
I aim to maintain qualities from both adult forms but different to the first and second 'marriage' and do this by using the following drawing actions (also used in 'adult' form): topology/ minus lower half, beak, branch (END). I then apply elements of the colour gradation method using pale purple.

Descendent five (right):
I aim to maintain qualities from both adult forms but different to the first and second 'marriage' and do this by using the following drawing actions (also used in 'adult' form): topology, scoop, slice, bifurcate, beak, bulge, observational element (END). I then apply elements of the colour gradation method using purple and blue.

<u>Isomorphogenesis no.8</u>
02/07/14:
This was the fifth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014. I decide to start with two observational elements and evolve forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:
I start the left column with an observational element collected on walk back from beach swim (a not yet unfolded flower as primitive and apply the following drawing actions to the form: multiply x two, add nucleus, rotate, change topology, thicken walls, apply grid transformation (oblique), slice, add observational element (END). I then apply Paul Klee's colour gradation method in six stages from from turquoise to green.

Right Column:
I start the right column with an observational element collected on walk back from beach swim (a - flower pod as primitive and apply the following drawing actions to the form: divide, add observational element, multiply, change topology, scoop, branch, add angle, add observational element, subtract multiple forms (END). I then apply Paul Klee's colour gradation method in six stages from yellow-ochre, purple to pink to green. The colour gradations are in different orders on either side of the form divide.

Descendent (top):
I aim to maintain qualities from both adult forms but different to the first and second 'marriage' and do this by using the following drawing actions (also used in 'adult' form): scoop, change topology, multiply, thicken walls, branch, bifurcate (END). I then apply elements of the colour gradation method using purple to yellow to green and pink.

Descendent (bottom):
I aim to maintain qualities from both adult forms but different to the first and second 'marriage'

and do this by using the following drawing actions (also used in 'adult' form): topology, scoop, thicken walls, observational element, nucleus (END). I then apply elements of the colour gradation method using green, ochre, purple and pink.

<u>Isomorphogenesis no.9</u>
03-07-14:
This was the sixth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014.
I decide to start two primitives: an abstract primitive a primitive form drawn from observation and evolve forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:
I start the left column with a dodecahedra primitive form and apply the following drawing actions to the form: add nucleus, begin divide, divide, multiply, add lateral shoot, apply grid transformation (oblique), twist, shrink, change topology, segment, add spines, add nodules to lateral shoot (END)
I then apply Paul Klee's colour gradation method in eight stages from earth green to pale green.

Right Column:
I start the right column with an with observational element (foxglove flower head) and apply the following drawing actions to the form: bulge, twist, horizontal shoot, beak, scoop, scoop (repeat), stretch (END). I then apply Paul Klee's colour gradation method from pink to purple in darker and lighter stages.

Descendent (left):
I aim to maintain qualities from both adult by using the following drawing actions (also used in 'adult' form): beak, scoop, stretch, add nucleus, add lateral shoot, add observational element - foxglove head (END). I then apply elements of the colour gradation method using pale green-acid green.

Descendent (middle):
I aim to maintain qualities from both adult forms but different to the previous 'marriage' and do this by using the following drawing actions (also used in 'adult' form): scoop, beak, add lateral shoot, add spine, add nucleus, add observational element - foxglove head, twist (END). I then apply elements of the colour gradation method using pale purple to pale green to pink.

Descendent (right):
I aim to maintain qualities from both adult forms but different to the previous 'marriage' and do this by using the following drawing actions (also used in 'adult' form): observational element - foxglove head, add nucleus, beak, lateral shoot, scoop, segment, add nodule, twist (END). I then apply elements of the colour gradation method using pink and purple.

Descendent (lower right):
I aim to maintain qualities from both adult forms but different to the previous 'marriage' and do this by using the following drawing actions (also used in 'adult' form): segment, scoop, observational element - foxglove head, add nucleus, add lateral shoot, add nucleus, add nodule (END). I then apply elements of the colour gradation method using pale green to pale pink.

<u>Isomorphogenesis no.10</u>
04-07-14:
This was the seventh work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014. I decide to start with the same primitive forms and evolve forms using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:
I start the left column with a taurus primitive form and apply the following drawing actions to the form: stretch, narrow, segment, bulge, add nucleus, apply grid transformation (oblique), twist, add observational element, scoop, clone, divide, curve (END). I then apply Paul Klee's colour gradation method in eight stages from ochre and blue gradation and outline in two directions.

Right Column:
I start the right column with taurus primitive form and apply the following drawing actions to the form: scoop, dent, rotate, change topology, divide, change topology, curve, begin spiral motion, curve, spiral, curve, spiral, crimp (zig-zag) walls, change topology, introduce lateral shoots, add nucleus, divide, stack, twist (END). I then apply Paul Klee's colour gradation method in ten stages from grey purple

Descendent (top):
I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): crimp walls (zig-zag), tendril extend, add observational element, lateral shoot, nucleus, twist (END). I then apply elements of the colour gradation method using grey with purple and ochre outline.

Descendent (bottom):
I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): twist, scoop, change topology, nucleus, observational element, lateral shoot (END). I then apply elements of the colour gradation method using yellow to ochre to purple outline.

Isomorphogenesis no.11
05-07-14:
This was the eighth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland,

2014. I decide to evolve three forms simultaneously, applying whichever action fits best to one of three pathways, using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left Column:
I start the left column with an observational primitive form (a living snail) and applying the following drawing actions to the form: begin divide, change topology, divide, dent, curve, bend, beak (END). I then apply Paul Klee's colour gradation method in seven stages from pale rust brown to Japanese green in opposite directions.

Middle Column:
I start the middle column with an observational element (pennywort leaf) and apply the following drawing actions to the form: scoop, thicken walls, contact divide, add nucleus, add symmetry-3 fold, add button symmetry, add small self similar parts, fractalize, crimp (zig-zag) walls, apply grid transformation (oblique) (END). I then apply Paul Klee's colour gradation method in seven stages from acid green to brown green to turquoise.

Right Column:
I start the right column with an observational element (fuscia flower head) and apply the following drawing actions to the form: bulge, add nucleus, apply grid transformation (oblique), multiply × two, bend, add symmetry-5 fold, multiply × three, subtract one layer, add lateral shoot, triangulate (END). I then apply Paul Klee's colour gradation method in seven stages from ochre to purple (all columns have seven colour colour stages co-incidentally).

Descendent (left):
I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): beak, nucleus, change topology, fractalize, lateral shoot, crimp (zig-zag) wall (END). I then apply elements of the colour gradation method using pale purple and acid green.

Descendent (middle):
I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form):crimp (zig-zag) walls, fractalize, nucleus, symmertry-6 fold, add lateral shoot (END). I then apply elements of the colour gradation method using rust and turquoise and purple.

Descendent (right):
I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): scoop, change topology, crimp (zig-zag) walls, lateral shoot, nucleus, crimp (zig-zag) walls, beak, button symmetry-3-fold (END). I then apply elements of the colour gradation method using acid green and pale rust and turquoise.

Isomorphogenesis no.12

06-07-14:

This was the ninth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014. I decide to evolve forms in two different lateral directions (upwards and downwards), using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left to right column:

I start the left column with an observational primitive form (yellow orchid head) and apply the following drawing actions to the form: twist, add lateral shoot, begin divide, change topology, scoop, divide, multiply, mirror, subtract one half, scoop, add tendril extend, crimp walls, segment, create inner circles, add nucleus (END). I then apply Paul Klee's colour gradation method in blue to grey in opposite directions.

Right to left column:

I start the right column with a pyramid primitive form and apply the following drawing actions to the form: divide, beak, melt, add primitive: sphere, change topology, slice, add nucleus, segment, curve, multiply, subtract-erase lower half, anthropomorphize (END). I then apply Paul Klee's colour gradation method in blue to grey in opposite directions.

Descendent (middle):

I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): scoop, segment, inner circle, tendril extend, nucleus (END). I then apply Paul Klee's colour gradation method in blue to grey in opposite directions.

Descendent (bottom):

I aim to maintain qualities from both adult forms and do this by using the following drawing actions (also used in 'adult' form): scoop, segment, inner circle, tendril extend, nucleus (END). I then apply Paul Klee's colour gradation method in blue to grey in opposite directions.

Isomorphogenesis no.13

08-07-14-

This was the tenth work made during a two week residency at Cill Rialaig, Co.Kerry, Ireland, 2014. I decide to evolve one form in a circular cycle and produce an 'asexual descendent', using my own 'Isomorphogenesis' adaptation of Latham's form synth system:

Left column:

I start the left column with a hyperbolic tree primitive form and apply the following drawing actions to the form: divide, multiply, subtract from ovoid form, dent, apply grid transformation (oblique), add nucleus, spiral, scoop, helix, invert, rotate, tendril extend, clone, stretch, add rods, scoop, crimp (zig-zag) walls, change topology, merge, fractalize, segment, divide, disperse (END). At this point form has evolved full circle back to the place of the hyperbolic tree primitive starting point. I then apply Paul Klee's colour gradation method in grey on left and grey red gradation on right.

Descendent:
I aim to maintain qualities from different stages of form change of the one adult form and do this by using the following drawing actions (also used in 'adult' form): zigzag, change topology, add nucleus, tendril extend, spiral, divide, scoop.

<u>The following details of drawing actions performed in Isomorphogenesis 1 (Actions pulled out of blue and yellow hats).</u>
<u>Task: draw Isomorphogenesis form with hat system and without hat system</u>.
Plan to work from hat: start with sphere/ 2 blue actions/ introduce new primitive from hat/ yellow actions/option to alternate between yellow and blue actions (at each stage consider variables: scale, material, texture, number, colour).

<u>Isomorphogenesis no.1</u>
I start with sphere
Blue action: stack
Blue: multiply
Blue: rotate
Yellow: clone (I choose to pass as I have already multiplied)
Yellow: add primitive to form, chose from hat: square
Blue: narrow (option to narrow form or just an element)
Yellow: mirror (pass)
Yellow: change topology- chose to change parts of topology by introducing more whole to the surface (genus 1, genus 2 etc.)
Yellow: subtract primitive from form - I decide to introduce new primitive and begin to evolve again. I realize that it is best to draw stages either as overlapping or distinct stages and then join. I realize I need to think about texture. Material at each stage for greater diversity.
Blue: bulge- repeat lower section and bulge
Blue: thicken walls - chose to thicken walls of entire upper form: feel the need to introduce a nucleus to the form and make an 'add nucleus' action
at this point the drawing is not making sense - it is nonsense - but carry on!
Blue: change topology- I have to pass-
Yellow: fusion (pass and may delete this action)
Yellow: bend - pass
Form has gotten too big for actions
Multiply - pass
Invert - pass
Yellow: introduce observational element - I can do this! I chose part of a dinosaur rubber on my desk and draw the spine

Yellow - inner circle (I make inner circle in select areas of the form)
Yellow: tendril extend (add tendrils to areas where I introduced holes/change of topology)
Yellow: twist - pass- one more then I quit!
Yellow: anthropomorphize - I add discrete hands, feet and eyes

Quit!

As I have drawn the series with many steps in one form I am forced to abort this drawing (learnt from this experience). I decide to develop one stage at a time after this drawing - and to keep texture/material and number in mind as variables… this is when I make a new hat for these variables… And I decide that I will start with a primitive which is not necessarily a sphere….Next drawing - sharpen my pencil - go!

Red: cylinder
Blue - rotate
Blue - thicken walls
Scale - small
Yellow: vertical shoot
Yellow- enfold walls
Blue divide
Yellow - scoop
Yellow- transform into another primitive- this may not work- pass- may delete this action..
Yellow: chain/ stack/ I do this by turning upside down/mirroring
Blue: stretch
Yellow: beak

Introduce new primitive (to then marry one evolved..)
Red -Taurus
Blue - change topology
Blue: bulge
Yellow: mirror
Yellow: overlay
Yellow: mirror
Bend
Grow growth pod
Blue - add angle – pass - decide to marry 2 forms that have been made following IFS actions…
Married forms looks less biological and more alien than the 2 individuals - more sci-fi..
Marrying is the action that humans are better at than computers…and it is fun!
Next drawing: draw making choices about the forms and actions I choose…
Read forms as developmental actions - although I have written the actions down here it is possible to read them from the drawings themselves..
Next drawing - make up - this works quicker…

C.1.1: Actions inspired by Thompson's grid transformations:
Vary horizontal lines
Vary vertical lines
Transform obliquely
Vary shape of grid
And from Thompson's work specifically in relation to cylinders (Thompson, 1992:85):
Expand, Narrow, Thicken walls, Thin walls, Lateral shoot, Vertical shoot, Bend, Coil, Enfold walls, Crimp walls, Bifurcate, Trifurcate, Transparency

C.1.2: Details of Actions derived from studying images of cell development and direct observation or 'reading' of the growth of plants
The following is a list of details of Actions derived from studying images of cell development and direct observation or 'reading' of the growth of plants:

Generate nucleus, Dent, Partial divide, Contact divide, Double contact divide, Break one contact joint, Double up, Break along one joint, Tendril at break end, Add segments create inner circle, Segments become inner wall, Spawn inside , Dent inner circle, Spawn nuclei/electrons/protons… Branch, Fractalize, Melt, Mirror, Stack, Chain, Segment, Divide (rounded: 1/2/3), Transform into another primitive, Spiral, Button (+ optional symmetry), Triangulate, Fusion/merge, Overlay, anthropomorphize, Change topology, Add symmetry, Add angle, Add teeth, Add wave form to edge, Rotate, Invert, Attach rod - straight, Attach rod - bendy, multiply

Terms derived from 'The Cambridge Illustrated Glossary of Botanical Terms':
July 2014: I decided to make a list of actions specifically derived from plant observations and discussions and also from 'The Cambridge Illustrated Glossary of Botanical Terms'. Root= primitive, leaf=kind of fractal behaviour, shoot=vertical growth/extension upwards or diagonally, new shoot=growth at angle to main shoot (line of growth), bud= result of growth- leaves transform with new potential, leaves grow around new spherical form…bud= new element with original element wrapped around, flower= bursting of new element+revealing/offering seed for new growth - for descendent / often including form and symmetry not seen in other part of plant - or hiding/concealed in leaf or bud… phyllotaxis= determines shape of bud+flower.

Ideas to make drawings which simulate plant growth 'flowering' at different stages.. different stages of life cycle represented in one image but also as continuum: decay…transformation in negative. Continued: burst, set, radiate, oxidize, tumerise, etiolate, hydrotope, cluster, appress (buds close to stem), imbrocate (bud nestles in shoot), caulesce (to have an obvious stem), pair, trigugate, trefoil, plicate:ridged, plier (fold), vernate: shape of leaf or shoot before it bursts, pervennate: to grow on shoot, regular rebirth, spathe: flower casing, distychus, continuity, discontinuity, introduce obstruction, introduce environmental change (change in temp/sun position etc.)- exogenous (change from outside)- indogeneous (change from inside), seed, shoot:

vertical/horizontal, stoloniferis, eyelet sewn, interflorence (collections of flowers), sprawling- gradually multiply flowering, influoresence-corynb, simple, umbel/ thermonasty: plants' reaction to warmth, compound umbel- cow parsley/ simple umbel- agapanthus.

Nouns: seed, sheath, tiller (blade), floret (no petals), stigma, rhizome, cataphyll (onion shoot layer), tunic (coating), cortex (membrane inside a root between the vascular bundle and the outside: piliferous layer), xylem, phyloem, pectinate: arrangement of the pine needles, replum, barb, pericarp, corm (underground root from which a plant perinates), palyn- pollen, palus, angulate, soften, VERB: vernate (shape of leaf)

C.2: Details of primitive forms of Isomorphogenesis

(Figure C.2)
The forms of Isomorph are in 3d and the forms of Isomorphology are in 2d (but could be in 3d) - so I draw equivalents (3d cylinder shares symmetry = bilateral symmetry; tetrahedron=three fold; cube=four fold; sphere= radial. Then I added a pentagonal prism as a 3d form of five fold symmetry; hexagonal prism for six fold symmetry; octagonal prism for eight fold; I also added icosahedron and ovoid to the radial 3d equivalents. I created a 2d ring as equivalent for 3d Taurus and I added a 3d branding form as equivalent for 2d tree, I also added a 3d helix and spiral as equivalents for 2d spiral).

C.3: Isomorphogenesis Workshop at the Natural History Museum as part of 'THE BIG DRAW' 2014

(Figure C.3.1)
See (Anderson, 2014b)

C.3.1: Isomorphogenesis drawing workshop with BA Drawing students at Falmouth University

January 2014
(Fig. C.3.2.1-C.3.2.5)

C.3.2: Isomorphogenesis Drawing Workshop at St.Ives School of Painting

13th May 2015
(Fig.C.3.3.1-C.3.3.9)

The following journal extract records and reflects the nature of this workshop:

This workshop followed an Isomorphology and Goethe drawing method workshop. After drawing Isomorphology forms as 3-d and 2-d and thinking about how their parts and how they combine- which triggers questions about formative process- we progress to gain insight into formative process through the drawing method 'isomorphogenesis' . To start this method we draw the abstract forms and symmetries of Isomorphology in three dimensions, which is *aided by our drawings of the Barbara Hepworth and Peter Randall Page sculptures, which brought our attention to the three dimensional qualities and complexities of abstract form/ amorphous form and helped us to think about 'topology' and how piercing form changes the nature of the three dimensional surface.*

10am
I introduce Isomorphogenesis as a continuation of the previous workshops on Isomorphology and Goethe method, as a way to evolve form through applying drawing actions (which are derived from biological and botanical growth). I do not present Isomorphogenesis as a true reflection of how things grow (the method does not integrate an analogue abiotic factors) but as a method gives us insight into the gradual nature of form change, through drawing practice. I also introduce Paul Klee's work and the concept of an 'abstract ontogenetic series' in relation to the Isomorphogenesis method. I also introduce Klee's colour gradation method.

11am:
We begin the Isomorphogenesis method, I guide participants through the following steps:
Prepare paper with translucent watercolour background (watercolour is used to emphasize gradual nature of form change)
Draw a three dimensional primitive/abstract form: this can be a three dimensional form of Isomorphology- a three dimensional 'character' derived from the Goethe method or a three dimensional form drawn from nature or art (specimens/field or sculpture - as in Hepworth) or select a drawing action from the red hat, which has examples of three dimensional primitives.
Apply form change as connected to previous stage- not like traditional developmental series where form is disconnected- but drawn as a continuum of form change.
Select drawing action from blue hat and apply action to primitive form
Select drawing action from yellow hat and apply action to primitive form
Select drawing action from yellow hat and apply action to primitive form
Select drawing action from yellow hat and apply action to primitive form
Keep going with yellow and blue until form is too complex to continue or feels like it is an adult….
Evolve another form in same way
Marry two adult forms or evolve another
Evolve progeny - child form or evolve another
Apply colour gradation
Make decision about next primitive: chose 2 of the same form - 2 different - one abstract – one observed - one from art and one from nature (back to Goethe's art/nature inform one another)
During the workshop, I remind participants of the importance of maintaining the three dimensional quality of Isomorphology forms as abstract forms in 3d and to imagine form development in 3d and not as isolated stages but as one connected transformation.

(As we have drawn from the Barbara Hepworth sculptures, I also offer the option to begin with a 3d Hepworth sculptural form, or an observed form, or a 3d form derived from the Goethe method or a 3d Isomorphology form). Each stage is then drawn as a modification and connected continuation of the previous stage, each drawing action integrated into the previous form as an evolution. Reasons to stop evolving include: too difficult, space restriction.

<u>C.3.3: Second Isomorphogenesis Drawing Workshop at St.Ives School of Painting</u>

10th September 2014

This workshop was structured as a three day workshop (8th-10th September) as described above. The following journal extract records and reflects the nature of this workshop:

10am

I began with an introduction about the development of the workshop and the Isomorphogenesis method. I talked about morphogenetic art, the concept of ontogenetic series and the motivation to learn about developmental process rather than object through drawing.

I asked participants to choose a primitive form from their work the day before with the Goethe drawing method and then I walked around the room and asked them to choose a (blue first) action from the hat. This approach worked well and walking around allowed me to help each participant grasp the method.

<u>Selected Feedback:</u>

'This would be good in schools- problem with need to make things look like things… suggest cutting out Goethe characters/primitives and collaging them…'

'You cant control it and you can feel yourself reacting against it but it is very interesting- you don't know what you are going to get… freeing as you forget normal way of doing things …'

One participant asks me if I mind if she shares the Isomorphology ideas with her art group. This is nice and I say that I would be very interested to hear how she communicates what she has learnt from the workshop and how the group take up the ideas.

(FIG-C.3.3.10- Feedback form)

<u>Response to Feedback Questions</u>

Which part of each method did you find the most enjoyable or interesting? Why? (Please expand)

Day 2, linking the natural study done on Day1 to the evolve forms after the visit to Barbara Hepworth sculpture garden. The sculptures inspired me to look at the natural forms differently (Yee).

How was the mix of studio work, field-work and trips to the Tate and Hepworth Museum?
Loved walking on the beach and collecting samples, Hepworth museum was also inspiring, I felt I was able to 'react' to the sculpture in a real historical way…looking at 3d form and abstract and that working backwards to natural form and then move forwards and this has helped me to my own Isomorphogenesis. (Jane)
Did the methods increase your sense of empathy for the natural world?
Yes I feel less repulsed by insects and I sense the strength of the force of nature pushing for survival. (Jane)
Do you feel that the method helped you to deepen your engagement with the specimen/natural world?
Yes the sense of interconnectedness have been experienced by simply observing describing and evidencing – moving into Isomorphogenesis of making something that did not previously exist is deeply satisfying (Jane)
Do you feel the method helped you to 'know' the specimen and/or natural world in a new or different way? If so, could you try to describe this new insight?
I like the whole concept of the conceptual forms abstracted from nature in primary and symmetries forms. It had made me looked at all natural forms in formation format. Example, I do not just see nice flower but the symmetry formation of the flower, etc. Day 2 was when I made the conceptual leap from observation to abstraction after the Hepworth garden study. After that, the recombining concept was easy to understand and follow. (Yee)
Did the methods increase your sense of empathy for the natural world?
Yes (see above). Also after this course I went out to purchase a copy of D'Arcy Thompson 'On Growth and Form' to get a better understand of the natural world. (Yee)
Do you feel that the method helped you to deepen your engagement with the specimen/natural world?
Yes, as stated above, I look at the nature with more child-like questions in mind, like how, what and why. How it is formed? What is it for? And why it is formed like that? (Yee)
Do you think this method could be useful in your artistic work? If so, how?
Yes, it helps to expand the artist mind and explored different ways to interpret the natural forms. (Yee)
If a follow up workshop could be programmed, how would you like it to develop what you have learnt during this course?
The 3 days course was intense hence there were not a lot of time for us to reflect recombining forms during the course. I learnt all natural form can be viewed in the Isomorphic classification format and hope to bring this into other aspects of my art work (Jewellery designs).
Was the background information and talk about Isomorph ology, Goethe and the Anderson's own method interesting? How was the delivery?
The delivery was articulate, enthusiastic and enjoyable....maybe a bit more time for slides to understand Paul Klee's work? and the ideas behind Hepworth's
Any further comments, overall reflections?
My most enjoyable course at the School due to your skill, enthusiasm, youthful new ideas, and

your follow up with photos and emails after the course... a first time this has happened in my experience.

'This course has been the best course I have ever attended! It's mind blowing- the creative practical work has and will assist my personal development and has enhanced my identity as a human being. I can see that I can apply the methods to my art practice and my life in general.' (Jane Moore)

'The teacher was excellent. She loves her subject and it shows in her way of teaching.' (Janet)

'Very clever at bringing together different abilities and giving everyone the confidence to come away feeling a sense of achievement.' (Rowena)

'Will go away extremely enriched by the experience Gemma has given me.' (Barbara)

'I start at the Art Academy on the 16th of September and will follow through with my own project work from late October to early November with a presentation in early November. It is my aim to study Morphology and Isomorphology for the whole year culminating in a summer exhibition at the Art Academy in June/July 2015. I will apply for MA studies in early 2015. Something "clicked" on the Creative Workshop; I sense that I am on a pathway that I have been seeking for the past 15 months'.(Jane)

'Gemma is very knowledgeable and adept at understanding every individuals requirements/needs' (James)

'Expanded the mind into new areas' (Barbara)

'Gemma was able to deliver a difficult concept in easy stages' (Diana)

<u>C.4: Klee colour gradation method</u>
(Figure.C.4.1 and C.4.2)

<u>C.5: Blue and yellow rules</u>
(See Figure C.5)
Blue rules are underlined and non-underlined rules are yellow

<u>C.6: Exhibition documentation and Process Biology publication images</u>
(See Figure C.6)

Figure C.1-C.8. ANDERSON, Gemma, 2014. Isomorphogenesis process during Cill Rialaig Residency. Photograph.

Figure C.1-C.8. ANDERSON, Gemma, 2014. Isomorphogenesis process during Cill Rialaig Residency. Photograph.

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Figure C.1-C.8. ANDERSON, Gemma, 2014. Isomorphogenesis process during Cill Rialaig Residency. Photograph.

Figure C.1-C.8. ANDERSON, Gemma, 2014. Isomorphogenesis process during Cill Rialaig Residency. Photograph.

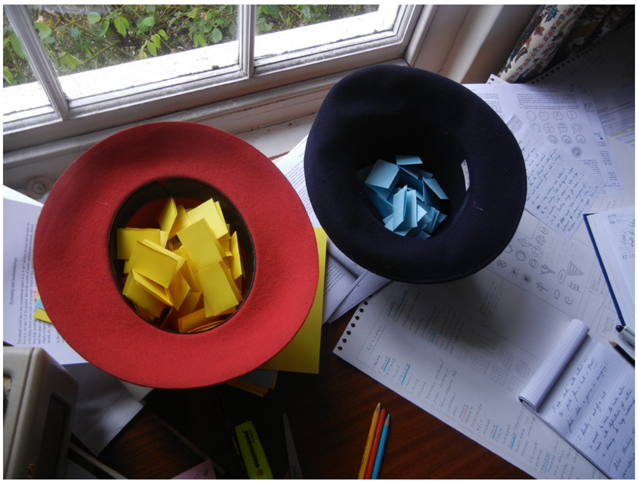


Figure C.1-C.8. ANDERSON, Gemma, 2014. Isomorphogenesis process during Cill Rialaig Residency. Hats. Photograph.

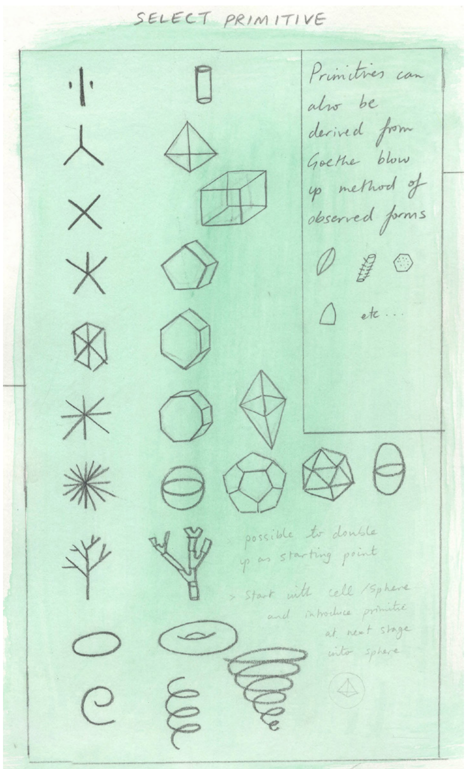


Figure C.2. ANDERSON, Gemma, 2014. Isomorphogenesis primitive forms. Pencil on paper and watercolour.

Figure E3.1. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at the Natural History Museum, London. Photograph.

Figure C.3.2.1-C.3.2.5. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop with BA Drawing Students at Falmouth University. Photograph.

Figure C.3.2.1-C.3.2.5. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop with BA Drawing Students at Falmouth University. Photograph.

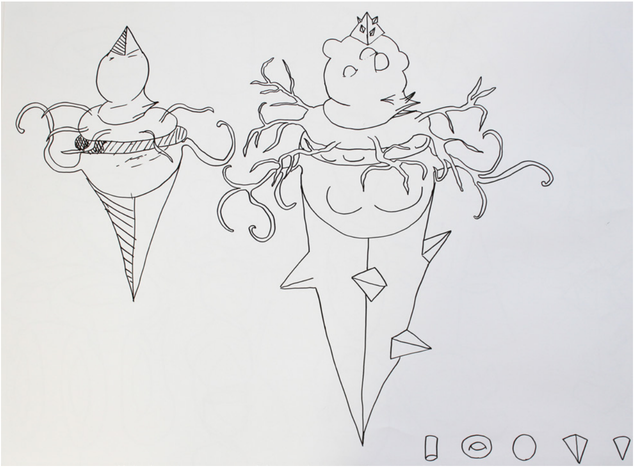


Figure C.3.2.1-C.3.2.5. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop with BA Drawing Students at Falmouth University. Photograph.

Figure C.3.2.1-C.3.2.5. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop with BA Drawing Students at Falmouth University. Photograph.

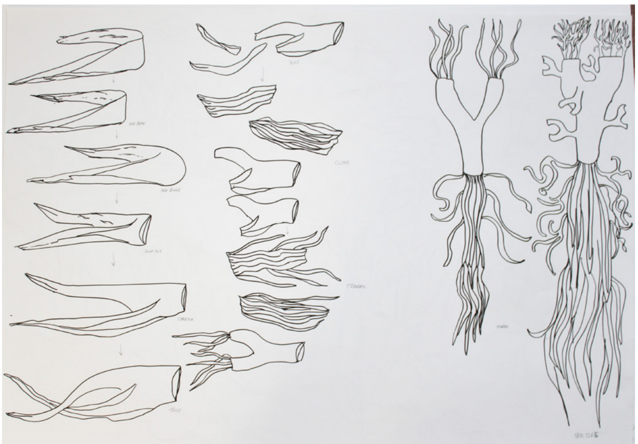
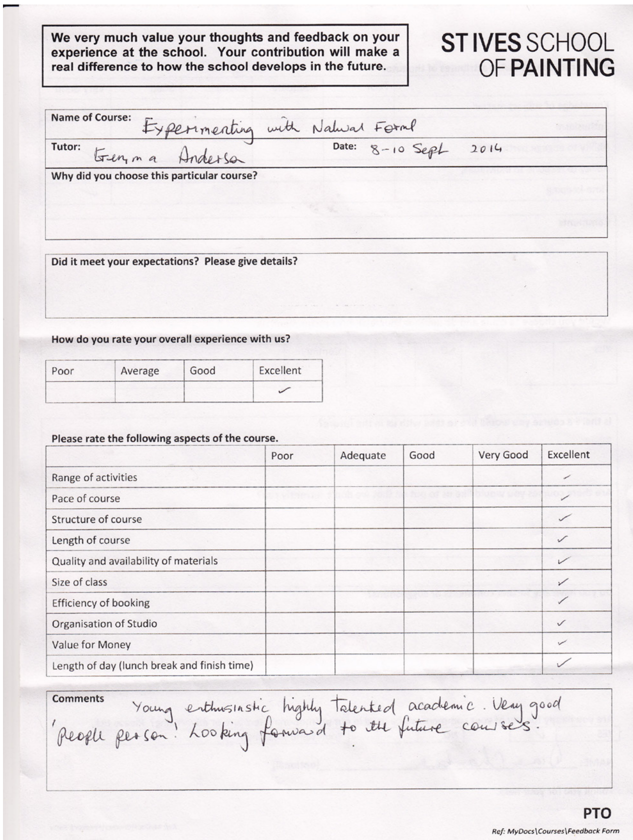


Figure C.3.2.1-C.3.2.5. ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop with BA Drawing Students at Falmouth University. Photograph.

Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.



We very much value your thoughts and feedback on your experience at the school. Your contribution will make a real difference to how the school develops in the future.

ST IVES SCHOOL OF PAINTING

Name of Course: Experimenting with Natural Form

Tutor: Gemma Anderson **Date:** 8-10 Sept 2014

Why did you choose this particular course?

Did it meet your expectations? Please give details?

How do you rate your overall experience with us?

Poor	Average	Good	Excellent
			✓

Please rate the following aspects of the course.

	Poor	Adequate	Good	Very Good	Excellent
Range of activities					✓
Pace of course					✓
Structure of course					✓
Length of course					✓
Quality and availability of materials					✓
Size of class					✓
Efficiency of booking					✓
Organisation of Studio					✓
Value for Money					✓
Length of day (lunch break and finish time)					✓

Comments Young enthusiastic highly Talented academic. Very good 'people person'. Looking forward to the future courses.

PTO

Ref: MyDocs\Courses\Feedback Form

Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.

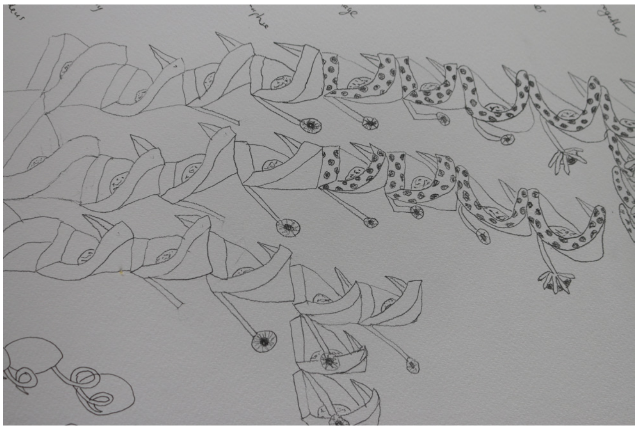


Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.

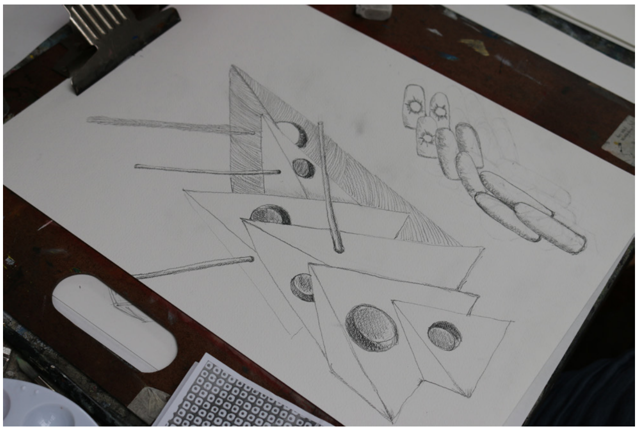
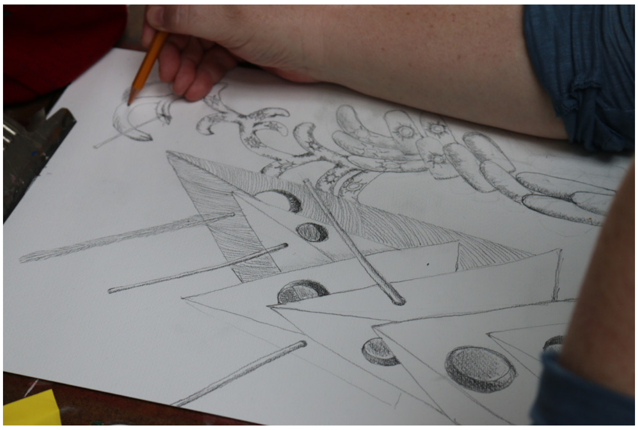


Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.



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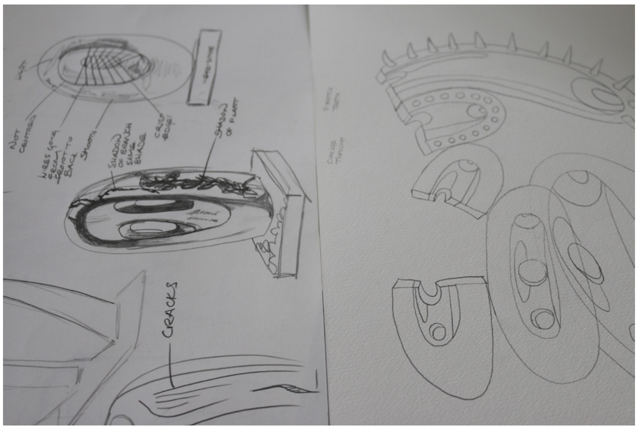

Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.

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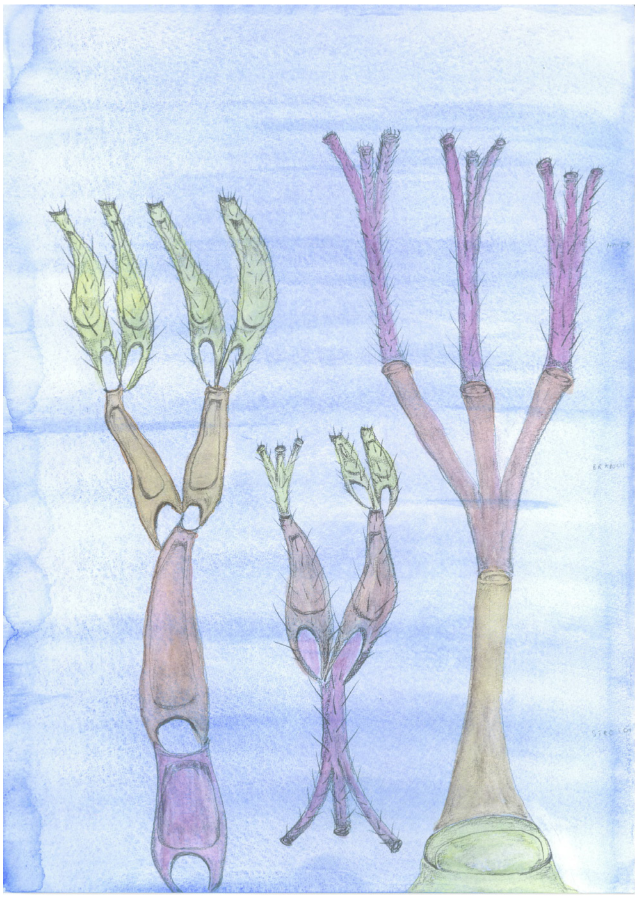

Figure C.3.3.1- C.3.3.10 ANDERSON, Gemma, 2014. Isomorphogenesis drawing workshop at St.Ives School of Painting. Photograph.

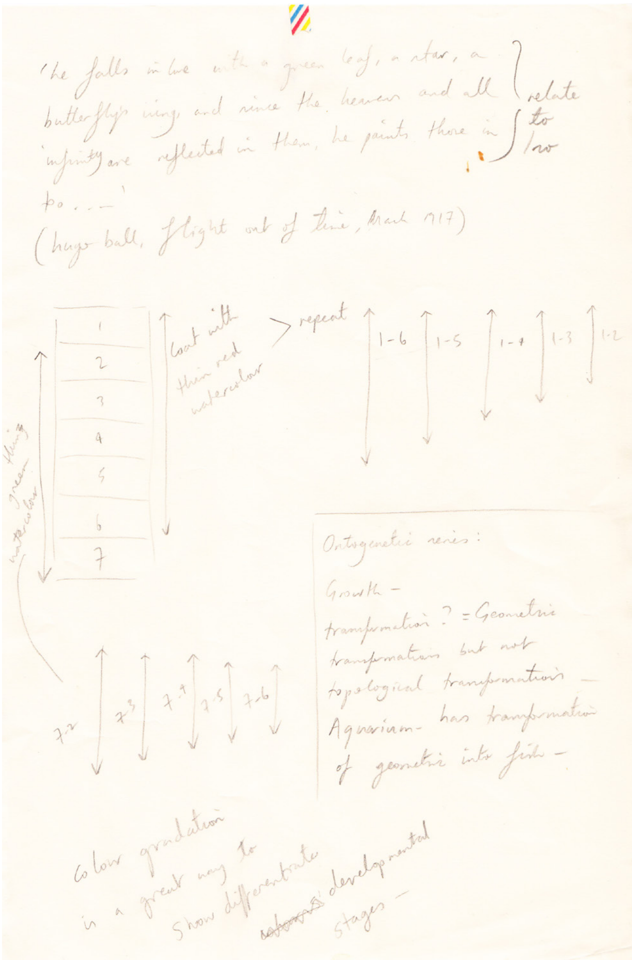

Figure C.4.1. ANDERSON, Gemma, 2014. Paul Klee colour gradation method drawing. Pencil on paper.

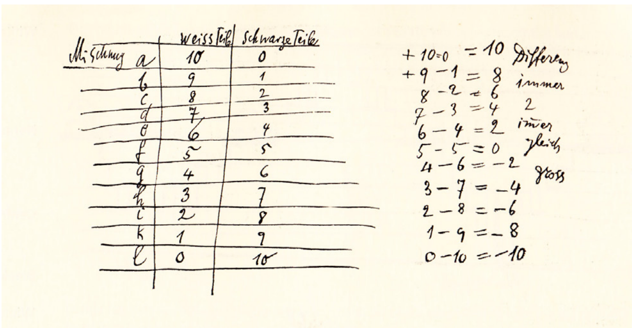

Figure C.4.2. KLEE Paul, 1932. Colour gradation method drawing. Pencil on paper.

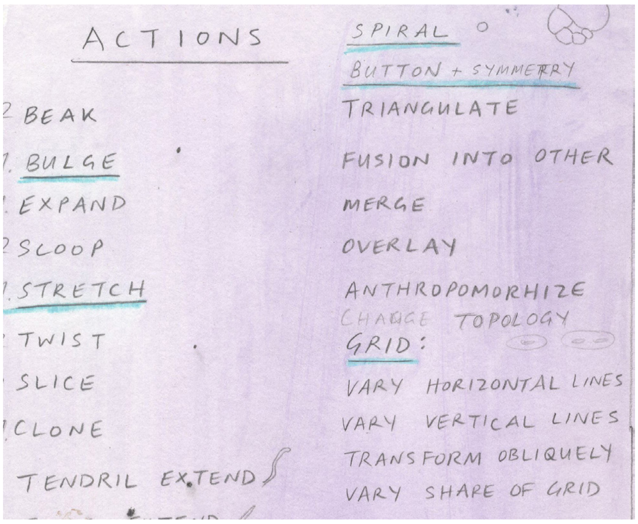

Figure C.5. ANDERSON, Gemma, 2014. Blue rules underlined, yellow rules not underlined. Pencil on paper.

Figure C.6.1-C.6.4 ANDERSON, Gemma, 2015. Isomorphogenesis series installed in 'Crooked Rain, Crooked Rain' exhibition, Centre for Contemporary Art, Derry. Photograph.

Figure C.6.1-C.6.4 ANDERSON, Gemma, 2015. Isomorphogenesis series installed in 'Crooked Rain, Crooked Rain' exhibition, Centre for Contemporary Art, Derry. Photograph.

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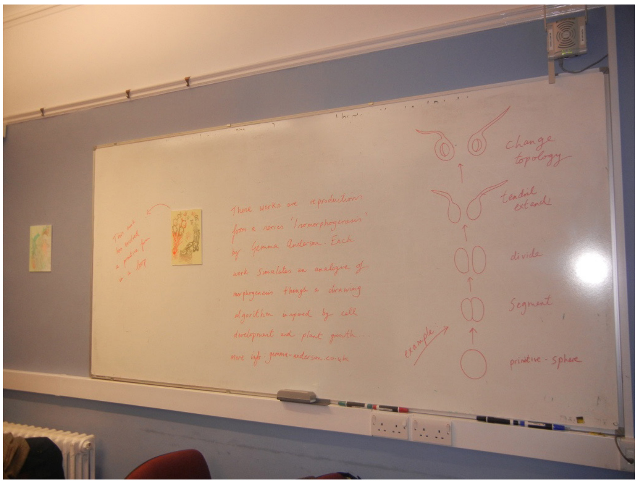

Figure C.6.5-C.6.7 ANDERSON, Gemma, 2014. Isomorphogenesis series installed in 'Process Philosophy for Biology' workshop, Egenis, Exeter University. Photograph.

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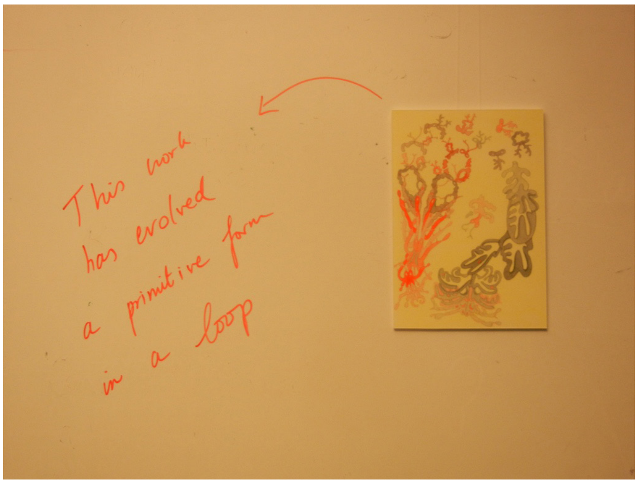

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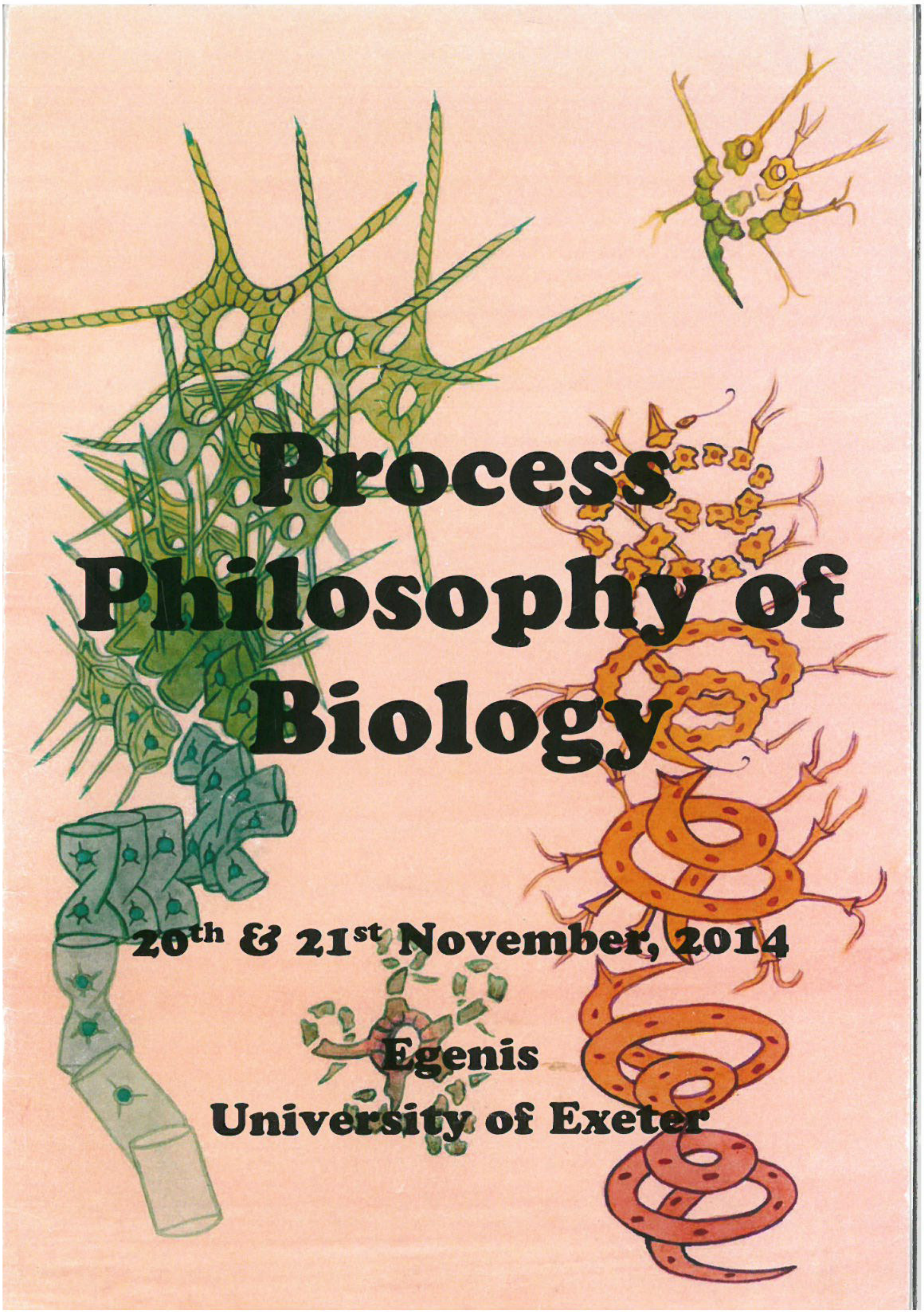


Figure C.6.8. ANDERSON, Gemma, 2014. Isomorphogenesis no.4 on the cover of the 'Process Philosophy for Biology' workshop booklet. Egenis, Exeter University. Photograph.

Appendix D: Cornwall Morphology and Drawing Centre – feedback and supporting material.

This appendix supports chapter nine 'The Cornwall Morphology and Drawing Centre', with material about the workshops and talks, which shared the drawing methods of this research with a wide audience. The project has also been shared through a new drawing research journal in the article 'Drawing the real and the unknown' (Hernly, 2015b) and a comprehensive web archive project (Anderson, 2015c). The following sections are indicated at different points in chapter nine.

D.1: Images of participants drawings from workshops.
D.2: Educational handout on crystal systems.
D.3: Feedback from workshops.
D.4: CMADC Student Placement Report.

<u>D.1: Images of participants' drawings from workshops (Fig. D.1-Fig.D.1.3)</u>

<u>D.2: Educational handout on Isomorphology (Fig.D.2)</u>

<u>D.3: Feedback from workshops</u>

After the 'Isomorphology of the Lizard' workshop one participant reflected on how the workshop fed into their own artistic practice:

> It was my interest in the repetition of form explored again in this series - http://williamarnold.net/The-Magnolias-Of-Wilfred-Aldwych along with wanting to learn more about botanical fieldwork from beginning the Edgeland Botanical series.
> After observing the specimens through the microscope and realising that the image could be photographed simply using a phone camera or compact camera - especially as this results in a circular image area - I had the idea that I would make some more of the Tin-can Firmament works and at the same time collect plant matter from the locations in which the cameras were placed to observe any repetition of form that might occur. This was the work that I made specifically for the Cultshare show (Photographer).

<u>D.3.1: Feedback from 'Drawing the Six Crystal Systems' workshop</u>

When asked to describe how the handling and drawing of models and mineral specimens helped the understanding of mineral form, participants responded:
'This mode of scientific and creative observation allowed me to understand both the miniscule and giant scale at which these beautiful minerals form … the models did provide an educational basis for the perfect and theoretical form these crystals are based on' (GCSE student).

'[…] wonderful to translate 3D forms into 2D lines, which helped to observe how curved shapes can be made from straight lines' (Artist).

'It was helpful to see the progressive nature of distortions/modifications of a cubic surface and how this can then be observed in more complex, real crystals' (Data analyst).

'Being able to look and to handle stimulated me and encouraged me to draw'(Lecturer).

'It was useful to see the idealized form in comparison to the natural form as a way of thinking about perfection' (Yoga teacher).

'[…] helps to understand form, texture, weight and lustre' (Designer).

'Handling the mineral specimen helped me to understand what the models are actually showing, but then handling the models helped me to see the diversity of geometrical shapes nature has invented' (Illustrator).

'I was able to move the models about and look at them in a 3D way, helping to understand the system of the form and how the shapes within it fit together' (Artist).

'Being able to see the model and the real life representation together highlighted the variations created by the environment where the mineral was formed. Where symmetry/shapes where not so clearly developed in the specimen, the models helped to see them' (Science student).

'Handling and drawing the different models and specimens taught me a lot about the different structures through close observation and the 'formative' process of the drawings' (Illustrator).

'I found it useful being able to turn the model in my hand to see how the structure works. When drawing a complicated collection of crystals the models really helped to identify the different structures […] it would be nice to see/draw crystals at different stages of development' (Illustrator).

'I noticed more about the 3D shape by feeling the specimen for the different planes' (Scientist).

'It helped to be able to handle and feel the 3d qualities of the specimen and models. The models were imperfect too, interesting connection with the specimen' (Drawing Lecturer).

'Seeing the models helped to understand the full diversity of crystal forms' (Drawing Lecturer).

When asked about the difference of working from the microscope (a 2d view) and the specimen (a 3d view) participants responded:

'The microscope enabled me to comprehend the seemingly miniscule and strange gigantic scale at which minerals and crystals form' (GCSE student).

'The microscope image took me straight to the macro viewed microscopic 2d image somehow suggested a larger landscape than the small pyrite crystal (Yoga teacher).[1]

'Drawing from 2d microscope view to 2d paper is less stressful than converting the 3d reality into a two dimensional image'(Data analyst).

'It was great from a learning perspective, the balance of narrative, concept and the kinaesthetic' (Designer).

'With time my two small mineral specimens could have become a mountain range!' (Artist).

'This workshop opened my imagination to the living underground' (Art student).

D.4. Student placement report

The following is an excerpt from Falmouth University BA Drawing student Minna Gawler Wright's Placement Report about her experience at CMADC:

> My placement has been a learning experience within two very different environments, but which share similar lines of enquiry; learning about the natural world. The first week was spent with artist Gemma Anderson in her studio in Helston, gaining knowledge about the process and development of her working life. Her approach to drawing is very much on a similar wavelength with mine; I can really relate to her work, so it was in incredibly valuable experience to understand more about what she does and how she makes a living out of it. It helped me make decisions about how I want to work in the future. It is a busy mixture of individual practice and research resulting in exhibitions, collaborations with various mathematicians and scientists, artist residencies, promotions, publications and teaching (educational workshops, talks and lectures). She is also studying for a PhD.
> The second week I worked at Leeson House Field Studies Centre in Dorset, an organisation built to teach primary to A-level school groups environmental education, covering geography and geology, history, maps and team building, living organisms, creative and sensory exploration, and local walks. It is run by the Dorset County Council Outdoor Education Service to give students learning opportunities outside the classroom. My work

1 This participant populated the micro which she drew as a landscape with drawings of the macro pyrite specimen which became a kind of city.

involved running drawing projects with groups of students, helping them gain knowledge of the mineral, vegetable, and animal specimens they encounter in a visual way. Having been taught at the centre when I was a young child, I felt the current pupils could gain a lot from this. The idea stemmed from Gemma's work encouraging scientists to draw their specimens to enhance their knowledge, and I wanted to see whether I would like to work in education in the future.

The education Gemma provides compared to senior tutor Mike Gould at Leeson House is of similar content, however they teach from very different angles, and have different goals and limitations. Gemma's work is personal to her and her drawing practice, and she promotes drawing in scientific education and research. Her workshops are about her personal research, and the importance of drawing in mathematical and scientific learning. It is very intuitive, and plays to the student's imagination in learning, encouraging them to learn independently through doing. Senior tutor Mike at Leeson House is bound by specific workshops to appeal to the school curriculum. The process of teaching these specific workshops repeatedly over the years has led to them being very structured and planned. The students are given specific experiences and taught as much as possible, but with little room for any individual experience in exploration.

With Gemma I was involved in a range of activities with Becky Danning, concerned with ordering and setting up her studio for a launch event. This consisted of painting the studio walls, testing microscopes, ordering and organising mineral specimens, and making posters for workshops and the launch event of the Cornwall Morphology and Drawing Centre (CMADC). Ordering the minerals was a chance for us both to learn more about Gemma's own developed practice of isomorphology – the ordering of specimens by their physical appearances. A lot of her work is based on the appearance of certain distinct forms in nature, which translate through animal, plant, mineral and vegetable types. We settled on three main categories of minerals: striped, spotted, and plain markings, which seemed to cover most specimens. Almost subconsciously we lined them up along the table in their categories – there was something very pleasing about this way of ordering, and drawing them in a line. I think this is to do with the way we read left to right. It also got us thinking about all the places the minerals had come from, who found them, and how many people had pondered over them. The almost infinite age of these specimens was made evident by the old labels, and boxes we found them in. The specimens looked like they could have just been collected, but their labels told a very different story. The age of the labels was dwarfed by the age of the minerals. We also found mineral specimens which fitted into Gemma's isomorphology categories. It made me really appreciate their diversity of form, texture, and content of fossilised organisms and plants, and drawing them built on this. Testing out the microscopes by looking at some slides of minerals was really interesting – I'd never seen minerals under a microscope before and I was astonished at the brightness of the colours, and the geometrical formations were almost unreal looking; some look like pure glitter. I would love to look at these more, and draw from them at some point – they reminded me a bit of my systems drawings. I would be a great start to a continuation of systems in a future project.

I spent some time on poster design, which turned out to be a worthwhile experience because of the amount I learnt by doing. With each new design, the work became more refined as I built on previous successes, and new ideas came to me. It gave me a lot of respect for designers; every little detail matters in the readability and feel of the poster. I looked at Bauhaus posters, which are so beautifully slick, however this level of simplicity was hard to achieve because there was a lot of information that had to go on the poster, and I've learnt less is more when it comes to readability. This has lead me to a compromise between what Gemma wanted, and what was actually achievable; I created sets of two posters, one to grab attention with the main information, the other to go into greater detail. The posters have now gone to a professional designer to be finalised; this has made me realise the level of professionalism that constantly needs to be maintained in Gemma's work.

Although I learnt a lot through the tasks that Gemma set us, the week showed me that a beneficial work placement doesn't necessarily mean creating anything physical for myself. Making contacts with people, and learning about how they work is essential in the creative world, where many people have to be their own boss and create their own jobs. I have realised that working entirely on your own can only achieve so much; knowledge and inspiration has to ultimately come from outside sources. It is also about connections creating opportunities, and this proved true as Gemma has made me her assistant for the future drawing projects she is going to teach in her studio. I am incredibly excited about this; it's going to be an incredible opportunity to learn more about what it takes to be a practicing artist, not to mention learning more about her work and the theory behind it, personal and admin skills, and possibly experience in teaching. I am also hoping to share the skills I already have, and my personal ideas and experiences.

Throughout the week the most interesting and useful knowledge and inspiration was gained through conversations with Gemma, about her working life experiences and opinions. She has a lot on her plate. She had applied to the Welcome Trust for funding for her studio, but the application was declined, based on the fact that her aims for the space weren't what they wanted. It seems a frustrating fact of life for many artists, that although they are their own boss, they have to work around ideas other people have for them if they need support. In this case, Gemma's aims of using the space for learning were rejected in favour of her individual practice.

Gemma was quite insistent on us photographing the work we have been doing, and taking photos of us and her in the studio space – a concept I am finding quite unnatural at the moment. It's almost awkward, but I've realised how essential it can be for recording your working life and showing yourself as an interesting, hardworking individual. No matter how much I dislike the concept of art as a business, a product, unfortunately you still have to succumb to its rules in order to promote yourself, make yourself known and heard as an individual, and eventually this will contribute to an audience's interest. Art is an incredibly personal thing, and I guess viewers do want to get to know the artists as people because it contributes to their understanding of the artwork. Even so, it is a weird concept to sell yourself as an interesting person in your beautiful studio. It's not just about the art you create; it's about the world you create around yourself. Art is after all an extension of your own thought. If you sell art, you sell your personality and your view of the world. In order for this view to become desirable art, it has to be interesting and desirable in its own right. More interesting conversations with Gemma have further elaborated on this. I am beginning to realise the extent of influence art has on an artist's personal life. Creativity and inspiration have to be looked after and nurtured, and therefore it is essential to look after yourself. In the past few years I have started practicing meditation, which has been an incredible experience but I've barely scratched the surface. Gemma said it is essential to her, and makes her able to cope with the stresses of her working life far better. The work she does requires a huge amount of focus, and meditation trains your brain to focus better. It is very important in maintaining a healthy outlook on the world. From experience around creative people, it seems we tend to be quite emotional. It is essential then to have a strategy for not letting emotion influence our creativity in a negative way. I have come to realise though, that drawing can be a meditation in itself. I also asked Gemma about how she feels working alone for long periods of time; a concept I struggle with. I concentrate better when others are working around me; wilfulness to work, thinking about things in a deeper way, and seeing perspective is greatly reliant on having others around to share opinions. Gemma says that working successfully alone comes with experience and confidence, and therefore a strong vision to work towards. But also trusting your judgements and not relying on other's interest to fuel your own. It takes perseverance. We also talked about dissertation ideas. Gemma is working on a piece about line as part of her PhD, and she says line is a physical way of thinking. It's a good way to connect lines of thought in your head by walking, which in itself is a physical way of making a line.

Finally, what I have realised from working with Gemma is that drawing really can be related to any subject you want it to be, and will enhance your knowledge of that subject. You can be as academic, or metaphorical and spiritual as you like, which is incredibly exciting. I'm looking forward to the chance to really explore some interesting subjects through drawing. I love the intellect in Gemma's practice; her work is very clever as well as beautiful, and she has had the chance to work with some truly interesting intellectuals, tying their knowledge together though the more accessible mode of drawing. Gemma says she is far too busy taking on too much, but she's not complaining, because it's what she wants to do. She has a great many opportunities which she has created for herself which I think is great; it's not work if it's what you love, and I am going to bear this in mind in future.

With each new conversation and experience I am getting from this work placement and this course, I feel I am becoming older, more knowledgeable and more excited and involved in the subject of drawing. I feel like I am collecting my experiences and really relishing what I have learnt from them. With this has come a greater understanding of my place, and my potential place within the art world, and I feel I have more of an idea of what it takes to be an artist. It is hard work, but spending time with Gemma has made me realise I want a similar working life for myself.

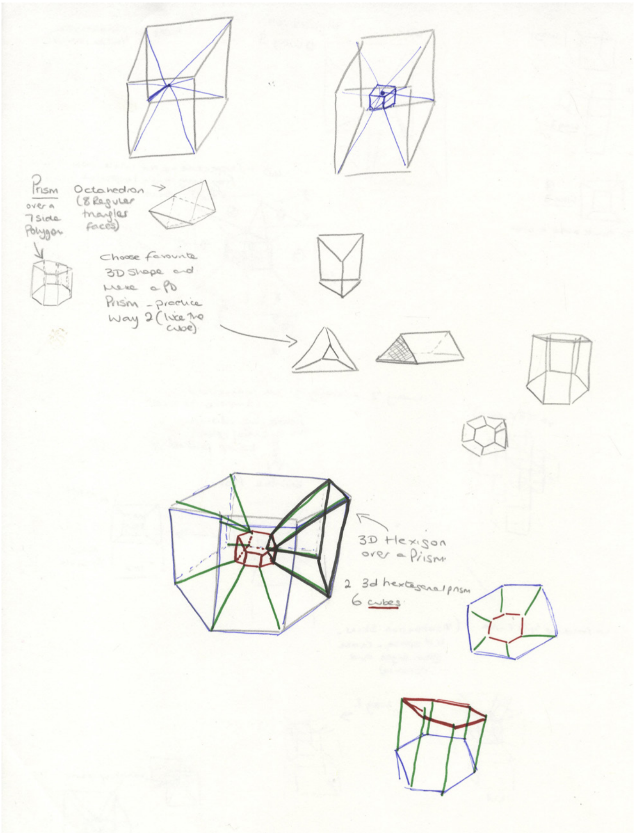


Figure D.1.1. 2015. Unnamed participant drawing from 'Drawing in the Fourth Spatial Dimension' workshop. Pencil on paper

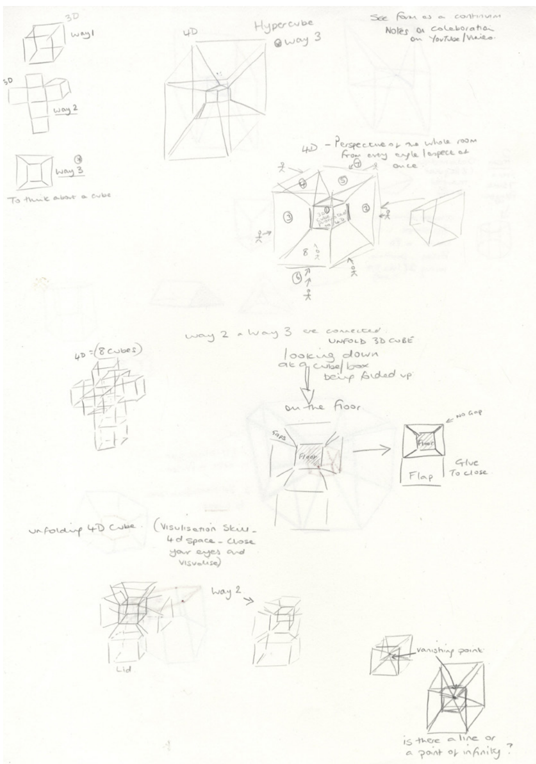


Figure D.1.2. 2015. Unnamed participant drawing from 'Drawing in the Fourth Spatial Dimension' workshop. Pencil on paper

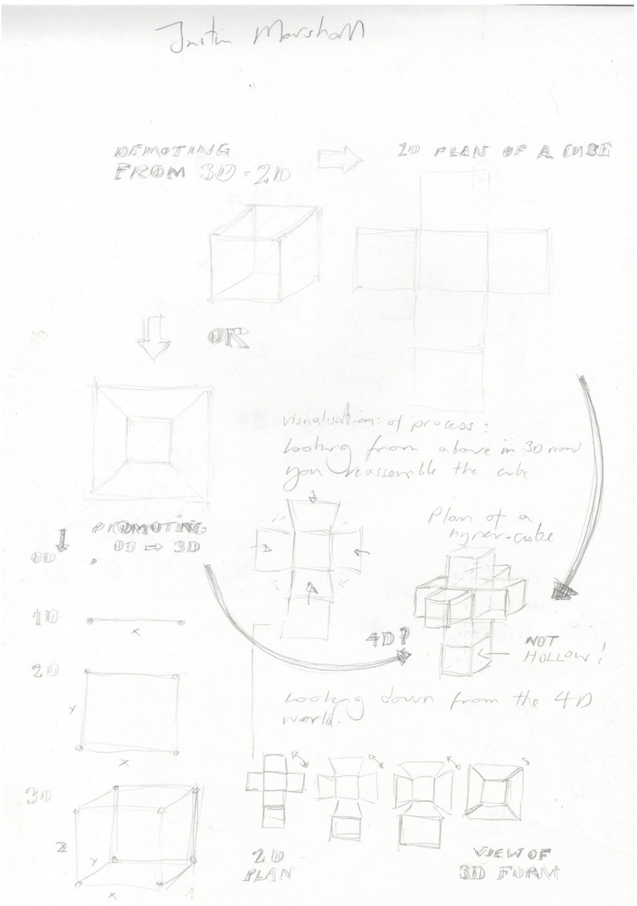
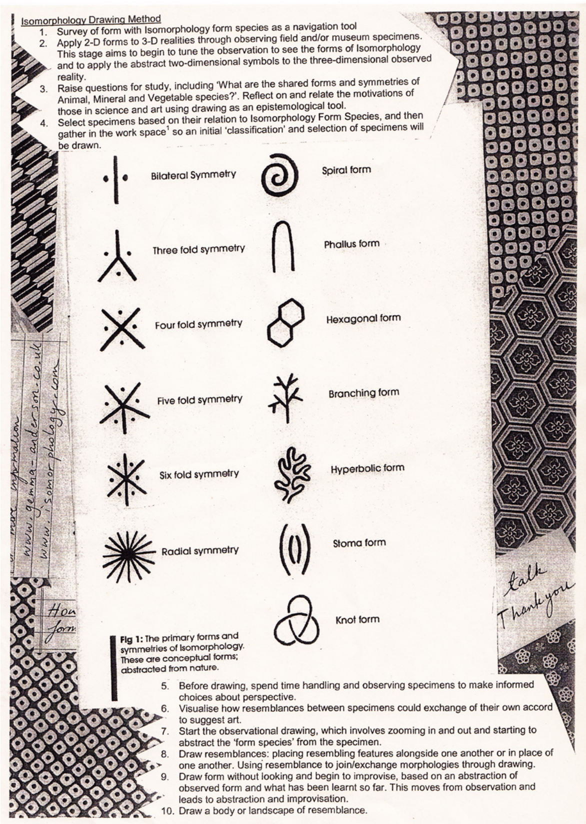


Figure D.1.3. 2015. Unnamed participant drawing from 'Drawing in the Fourth Spatial Dimension' workshop. Pencil on paper



Isomorphology Drawing Method

1. Survey of form with Isomorphology form species as a navigation tool
2. Apply 2-D forms to 3-D realities through observing field and/or museum specimens. This stage aims to begin to tune the observation to see the forms of Isomorphology and to apply the abstract two-dimensional symbols to the three-dimensional observed reality.
3. Raise questions for study, including 'What are the shared forms and symmetries of Animal, Mineral and Vegetable species?'. Reflect on and relate the motivations of those in science and art using drawing as an epistemological tool.
4. Select specimens based on their relation to Isomorphology Form Species, and then gather in the work space[1] so an initial 'classification' and selection of specimens will be drawn.

Bilateral Symmetry — Spiral form
Three fold symmetry — Phallus form
Four fold symmetry — Hexagonal form
Five fold symmetry — Branching form
Six fold symmetry — Hyperbolic form
Radial symmetry — Stoma form
Knot form

Fig 1: The primary forms and symmetries of Isomorphology. These are conceptual forms; abstracted from nature.

5. Before drawing, spend time handling and observing specimens to make informed choices about perspective.
6. Visualise how resemblances between specimens could exchange of their own accord to suggest art.
7. Start the observational drawing, which involves zooming in and out and starting to abstract the 'form species' from the specimen.
8. Draw resemblances: placing resembling features alongside one another or in place of one another. Using resemblance to join/exchange morphologies through drawing.
9. Draw form without looking and begin to improvise, based on an abstraction of observed form and what has been learnt so far. This moves from observation and leads to abstraction and improvisation.
10. Draw a body or landscape of resemblance.

talk
Thank you

Figure D.2. ANDERSON, Gemma, 2015. Isomorphology workshop method handout. Photograph.

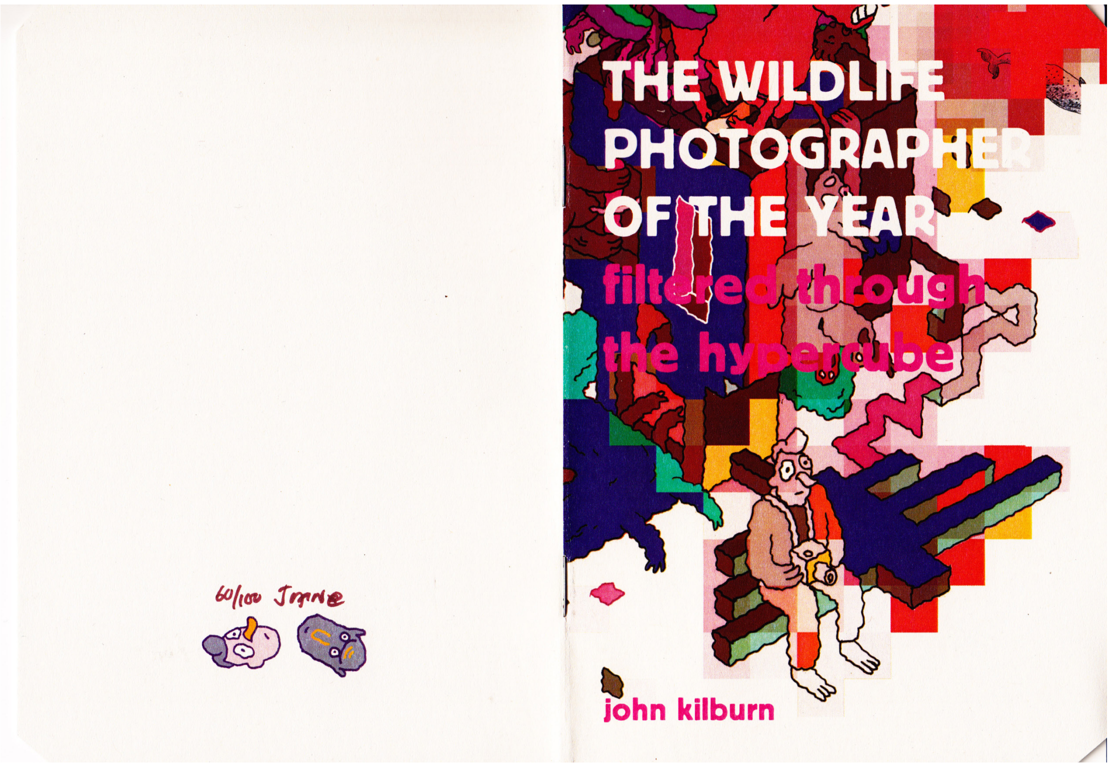


Figure D.3.1. KILBURN, John, 2015. 'The Wildlife Photographer of the Year: Filtered through the Hypercube'.

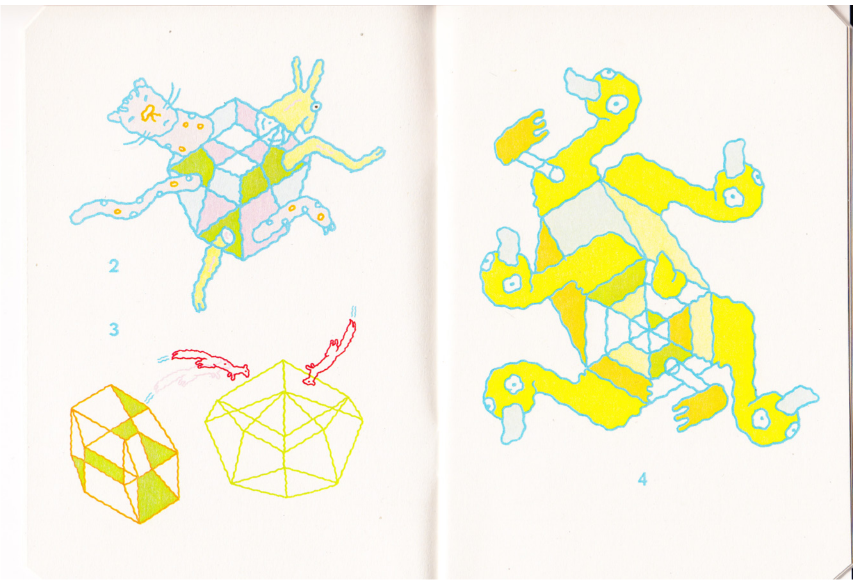


Figure D.3.2. KILBURN, John, 2015. 'The Wildlife Photographer of the Year: Filtered through the Hypercube'.