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Taking the Discussion Onward

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Receiving and reading the remarkable cluster of reviews of *The Poetry and Music of Science* (henceforth *PaMoS*) in this edition of the journal must rank among my most exhilarating academic experiences. To be engaged by such constructively critical, informed (far better than I), severe where necessary, pedagogically generous, creative and, above all, *interesting* thinking is a dream for any academic writer. When colleagues put such collective thinking towards the project that lies beneath and beyond all ‘interdisciplinary’ work – namely a united conception of knowledge – the extended discussion touches places where not only our minds, but also our hearts, find life and joy. So it is not the place of this final essay to answer, or respond in every point, let alone ‘rebut’ any of the forgoing pieces (it would not, even if I were qualified to do so) but to draw threads of discussion together and suggest the reading, thinking and writing that may constitute the next stage of responding to the questions raised or stimulated by the subject addressed in the book.

Rather than take the reviewers in turn, therefore, I will try to tease out a few of the many threads that one or more of them raise, and suggest a continuation of the conversation. Some concern themes touched-on but inadequately discussed in the book, others reveal gaping lacunae, others suggest ideas to develop or to clarify. I have necessarily had to make choices under the limitation of space – surely another book could be written in response to each review – but, guided by those issues that seemed to attract the greater number of voices, or which seemed to me most promising to pursue, I should say something more about: (i) historical context, including the origin of the ‘Two Cultures’ divide itself; (ii) cultural contexts of science and art; (iii) the ironic silence of *PaMoS* in regard to poetry; (iv) the differences, rather than the similarities, in creative processes of art and science, including the distinction between ‘creativity’ and ‘imagination’; (v) the social and institutional framings of science and art; (vi) computing and digital creativity; (vii) theological (and anti-theological) tropes in creativity and the fragmentation of disciplines. That ought to do for a start.

Historical Framings and Questions

The stance of *PaMoS* is variously described as ‘ahistorical’ (Whitworth) and ‘primarily historical’ (Huber). I think that the confusion may have two causes: firstly that, while drawing on historical examples, the book does not pretend to be a history, or even primarily concerned with historical questions. Secondly, its embedded polemic on the role of creativity in *science* chooses deliberately to stress continuities rather than differences. Fuller and Huber both point out unanswered historical questions, including the key puzzle of when and how the ‘Two Cultures’ paradigm emerged (in the West). I think these readers together imply that, although history is important to the story of human creativity in the book, that they take my reading of the human creative act to be as timeless and cross-cultural as human anatomy. This is not, fortunately, my claim, although when the task is to challenge fragmentation and an accepted emphasis on difference, the rhetorical stress is bound to be on unity and commonalities. The history of scientific imagination surely contains its continuities as well as its rapid shifts, its cross-currents as well as its slow evolutions. Without some notion of continuity, after all, there is no reference frame by which to detect difference and change. That said, these three reviewers and others make the point that, in investigations such as these, a proper appraisal of their cultural history is indispensable, and ‘timeless truths’ are chimeras. I should have been clearer, for example, that the remarkable appearance of a form of the ‘narrative of human creativity’ in Anselm in no way implies that he framed his task or visualised his metaphors in the same way that a contemporary thinker would, any more than the ‘Discarded Image’ of the geocentric cosmos left the palette of astronomical ideas unchanged between medieval and modern astronomers.

Prompted additionally by Hugill’s important point about digital creativity (see below), I am now surprised that I did not say more about the relationship between emerging technologies in history, and the stimulus that technology has always provided to creative imagination in both art and science, as well

as the technical contextualisation of the cognitive. There are implied examples of course, but a stronger cultural point could have been made. The musical example of Schumann's *Konzertstück* is a case in point: culturally its innovation fuses a Baroque form with a post-Beethovenian romantic style, but it would have been technologically impossible to attain its imaginary spaces (*pace* Hugill's dissenting and more critical reception of the piece) without the invention of the valve-horn (Zon's technical point here refers to the orchestral horns, as Hugill points out, not the solo quartet). The suggestive creativity that technology affords science finds fascinating personal locus in Hugill's 'cross-over' people, like Lamarr and Biro. One could add Lovelace and Turing, and think about how the mechanical has informed the mathematical and computational imagination, as well as the other way around.

A much more serious failure of emphasis on historical framing lies at the points where I draw on the full-bodied emergence of experimental scientific method in the 17th century. Although this lies behind and beyond the more focused discussion of its relation to new forms of fictional narrative (in chapter 4 of *PaMoS*), and of the heliocentric cosmos and visual imagination (in chapter 3), there is more to say on how the different thought world of that time offered paths for creative thinking that are no longer travelled today. Stephen Shapin in *The Scientific Revolution* nuances the mutual avoidance of 'presentist' construal of this history of science on the one hand, while being careful not to reject all continuities, on the other. He also, more successfully than many other historians of science, stresses the process and practices of making scientific knowledge, rather than a purely evaluating their outputs. One of the salient ways in which such practice differed in the 17th century from today, was in the customary routes to establishing consensus: 'It is quite possible,' Shapin writes (Shapin 2018), 'that many practical problems of scientific credibility were solved by a device as apparently simple as the gentlemanly code of honour' - a striking example of difference.

There are other aspects of early modern science that require as great a rethinking of fundamental assumptions of method. The power and reach of experimental method is so obvious to anyone educated in the occident today, that it is difficult to grasp how great were the intellectual obstacles in the way of adopting it in the century of Bacon, Boyle and Newton. The contemporary voice that most clearly helps us understand the almost-overwhelming case against the new 'experimental philosophy' is that of Margaret Cavendish. Her opposition to experimental method as a viable route to knowledge of the natural world is a repeated theme in her 1668 (2nd edition) *Observations Upon Experimental Philosophy*. The Achilles' heel of experimental *artificiality* is highlighted time and again; a good example is her discussion of various 'sorts of heat and cold' (Cavendish 1668 chapter 26):

For if men conceive that there is but one heat and cold in nature, they are mistaken – and much more, if they think they can measure all the several sorts of heat and cold in all creatures, by artificial experiments. For as much as a natural man differs from an artificial statue or picture of a man, so much differs a natural effect from the artificial ... Artificial things are pretty toys to employ idle time.

Strong words indeed! For Cavendish experiments are toys for the boys (she is unabashed to gender her argument, reserving the superior contemplative philosophy for women). Her voice really belongs at the centre of an early-modern comparison of science and literature for another reason – the argument was even more boldly put in arguably the first modern work of science fiction, her fantasy *Blazing World* (Cavendish 1666). Cavendish's rhetorical moves in both philosophical and fictional form juxtapose the artificiality and over-simplicity of experiment to the rich complexity and multiple forms of nature. Her preference in method is therefore for what she calls 'speculative' or 'contemplative' philosophy. It is all too easy today to overlook the inherent difficulty of human knowledge or conception of nature that persisted from pre-modern thought in spite of the innovations of the 15th and 16th centuries. However, there is an echo of continuity here too: Cavendish's 17th century suspicion of the over-simplifications inherent in experiment find resonance in 21st century arguments of the relevance of *in vitro* to *in vivo* methods in biology (*e.g.* Lorian 1988).

Picking up Fuller's crucial point about the continued experience of divergences within science within a deeper history of ideas, makes me think of Aquinas (*Summa Theologica*, 2020), who had long before

contrasted natural science to theology in terms that anticipate Cavendish's contrast of experimental and contemplative philosophy, or theology ('this science'):

This science surpasses other speculative sciences; in point of greater certitude, because other sciences derive their certitude from the natural light of human reason, which can err; whereas this derives its certitude from the light of divine knowledge, which cannot be misled: in point of the higher worth of its subject-matter because this science treats chiefly of those things which by their sublimity transcend human reason; while other sciences consider only those things which are within reason's grasp.

Even natural complexities that lie beyond 'reason's grasp' were therefore beyond hope for the scholastic mind. When Shapin meets the inevitable confrontation of Newton and Boyle, he quotes the Newtonian response to both Aquinas and Cavendish 'to bind assent in iron chains of mathematical and logical deduction, seeking to guide the mind along from necessary truth to necessary consequence'. When what is meant by 'theory' and 'experiment', and the relation between them, have all changed out of recognition in three centuries, it is indeed naïve to assume that a discussion of creativity in either can be completed without recognising that, and doing the hard historical work.

Perhaps the most interesting historical question raised (or at least implied) but assuredly not answered in *PaMoS*, as Huber points out, is the historical locus and reason for the 'Two Cultures' divide in the first place. She draws our attention to the fascinating 19th century precursor of *PaMoS*, Robert Hunt's *The Poetry of Science* (Hunt 1850) of which I was culpably unaware, and situates Hunt's possibility of consonance in the *findings* (in contrast to my emphasis on creative *process*) of poetry and science. The ground of hope for this she situates, in turn, within the natural theology of the time (but see also the discussion on poetry itself, below), that provided a foundational assurance that all paths to knowledge must lead ultimately to the same point. Her examples of Tyndall, Whewell and Hunt himself make the point that an explicit discussion of imagination in science was thoroughly alive in the 19th century (though, see Whitworth's careful historical nuancing of 'imagination' and 'creativity' – I and other commentators all fall into the trap of eliding them too easily). Fuller echoes the question, which he pointedly terms a 'Second Fall' in the history of ideas. One reason that I did not address this crucial issue in the history of Western thought is that I am completely unequipped to do so, but whatever and whenever the truth in the historical parting of ways, signposted by the amicable anxiety of Huxley and Arnold's early discussion, of which we are reminded by Huber once more, both theological and aesthetic developments must have played out.

Now when theology and aesthetics collide we surely ought, as others have urged me, to read Nietzsche more. The coincidence of the late 19th century proclamation of the 'death of God' and the loosing of the bounds of art and science as a sort of 'second fall', is too suggestive to be overlooked. At one point in *On the Genealogy of Morals* (Nietzsche tr. F. Golffing 1956, *What is the Meaning of the Aesthetic Ideal?*² 6,8), Nietzsche presents two opposing approaches to the idea of the beautiful, the first identified with Kant, the second with Stendhal. The fascinating aspect (to me at least) of the contrast is its proposed comparison of an impersonal and disinterested aesthetic of Kant to the personal, immersed and rewarding aesthetics of Stendhal, and the implied shift of primary aesthetic locus from observer to practitioner, from an externalised to an internalised experience. If Nietzsche is noticing a shift in the beautiful from the commons to the personal, then this move is indeed precisely opposed to the direction that Wordsworth anticipated could one day reconnect science with poetry. It is also a foundational move of late modernism that distrusts the claim of common truth as 'institutional' or even 'ecclesiastical', and points to the primacy of individual readings. These observations may be of relevance to the history question of the Two Cultures, but in any case bring us firmly into the domain of cultural framings of science, art and their processes.

Cultural Framing

The most telling cultural critique of *PaMoS* is the occidental situation of almost the entire narrative – *mea culpa*. Could a case for a common pattern of creative narrative be advanced in cultures of the

Pacific, of South and Middle America, East Asia, Australasia, India, the arctic circle and more? They are important questions, and I cannot offer answers (plurals because there needs to be a sensitivity to translating what we now call ‘art’ and ‘science’ into activities across cultures and histories in which nothing translates simply, and in the face of the additional need to differentiate practice and purpose). Leach advances, echoed by Barnie, the most salient challenge – and it is no surprise that the anthropologists see this most clearly – that the very divide between art and science that I have sought to bridge through both process and purpose, only arises in a Western culture that conventionally construes a separation between the human and nature, itself driven by a Western notion of transcendence. The alternative is a culture of flow, immersion and non-transcendent integration, of which anthropologists such as Ingold and Strathern (who was an interlocutor during the writing of the book) have spoken. A clearly articulated example (I am indebted to Leach for this quotation) is given by animistic belief systems (Arhem 2016; 3):

As opposed to naturalism, which assumes a foundational dichotomy between objective nature and subjective culture, animism posits an intersubjective and personalized universe in which the Cartesian split between person and thing is dissolved and rendered spurious. In the animist cosmos, animals and plants, beings and things may all appear as intentional subjects and persons, capable of will, intention, and agency. The primacy of physical causation is replaced by intentional causation and social agency.'

Ingold himself, and in this journal (Ingold 2018) hints at a ‘softer’, more compliant and connected way of doing science, inherited from both his mycologist father and his fieldwork north of the Finnish Arctic Circle. The lovely ‘alternative scientific imagination’ which would emerge in a culture where the stereotypical organism were a fungus rather than a mouse, points to the very different possible framings of both science and art (Ingold conflates them) when cultures collide. In the same vein, Australian anthropologist Veronica Strang (2015) writes that a ‘lack of separation between the human and non-human (or between persons and things) is common to many hunter-gatherer ontologies, and is generally coherent with a human-environmental relationship closely embedded in local material events’, also citing Descola and Palsson (1996). While this must be true in a strong cultural sense, there are separations that cannot be avoided (humans have skin – we are not Ingold’s fungi). The myth-making of ancient hunter-gatherers can only be guessed at from the symbolic artefacts that we possess, such as the wonderful Schwabian ‘Lion-Man’ from 50 000 BCE that I discuss in *PaMoS*. But both chimeras then, and rainbow-snakes today, generate stories, and stories move from separation to reconnection; we recognise them sufficiently to ask questions and to construe our ignorance – they are not ‘noise’ (in the sense of Kermode (1968)).

Of course hints of an immersive, connected, participative science are not entirely absent from *PaMoS* – I am recalled to my fascination when coming across Emmanuel Levinas’ preference of auditory, rather than visual, models for thinking about the world. A fascinating extension of these sensory metaphors brings us back to Nietzsche once again, who (see Babich 2003 – I am greatly indebted to Babette Babich for pointing this out to me) claimed that ‘science aims to interpret the same phenomenon through different senses, and to reduce everything to the most exact sense: the optical’ (Nietzsche 1986). He stressed the philological link between taste (*sapio*) and wisdom (*sapiens*). A suggestion of a ‘ladder’ of higher and lower senses connects by implication the immersion of smell – even more so than Levinas’ auditory connection – to the objective. My conclusion after the survey of *PaMoS* was that both immersive and distant perspectives were necessary, and both as fundamentally human. It is no surprise, once one has read Iain McGilchrist (2009), that some cultures will have developed one of them to the expense of the other.

There is a great deal more to do here, and surely a true cross-cultural comparison of human/non-human relationship will always escape the most sensitive anthropology, for everyone sees, in the end, through their own eyes. That the notion of a felt need to reconcile the human and the material finds resonance across very wide gulfs of geography and time was an earlier theme of mine (McLeish 2014) in a close reading of nature poetry in *The Book of Job*. Admittedly a foundational document of later Judeo-Christian tradition, this ancient Semitic text still escapes historical identification, and its origin is

very distant from the cultural framing of anything we might call ‘science’, yet readers today recognise its yearning questions of origin of snow, ice, lightning and the stars.

Poetry

Several reviews quite rightly, but gently, take me to task for announcing a titular theme of poetry then remaining all but silent about it. There are of course other reasons than a cover announcement for the need of serious work on poetry itself under the theme of the book. Huber locates the very origin of the Two Cultures divide – one of the hanging historical questions – with poetry itself (rather than in the novel or visual art). Bernie challenges my over-general claim that science has not, in contrast to Wordsworth’s hope and vision, inspired poetry, and adduces examples past, present and personal to make his case (I am grateful beyond words for the vision of a sifted flour-mist of angels). Whitworth calls on Coleridge’s distinction of ‘imagination’ and ‘fancy’ to describe respectively a grasping of reality and expressive whimsy, that parallels Fuller’s apposition of representation and expression. Both Fuller and Bernie see in poetry a medium which is its message, I think meant to present a stark contrast to science. Science is represented, expressed and transmitted in many media, however, some of which lie closer to, or are more entangled with, the message they embody (I would claim that an example of a scientific blurring of medium and message is found in the mathematical instantiation of a theory in physics, for example). We must continue a discussion that holds poetry and science alongside each other.

The literature contains a long, tense, but fascinating historical discussion of how poetry and science relate. Goethe thought that science arose from poetry, Poe and Keats cried that science eviscerated poetry like a vulture on so much carrion, or that it unravelled the wonder of a rainbow like a truculent toddler destroying the knitting (in support, perhaps, of Huber’s contention). Adding to Bernie’s examples, on the other hand, late modern scientist and poet Miroslav Holub thought that the two activities shared both discovery and energy, while early modern metaphysical poet John Donne drew on science as poetically enriching.

The reason that I put poetry on the title page of *PaMoS* was really that it describes my running hypothesis of *form* throughout the discussion. If poetry is the creative meeting of imaginative energies and ideas with the shaping constraint of form, then what could act as a better metaphor for the scientific imperative to describe the world in layered and connected details? In other words, what could call upon greater imaginative energies than the invitation to re-imagine the universe, and what could constitute a tighter constraint of form than to conform that imagination to the universe we observe? Science as poetry, or perhaps as a single, collaborative, and polyvocal poem. The reworking of the expression of a scientific hypothesis (I do not agree with Fuller that I, or scientists in general are ‘receptionists’ in his sense for just this reason) under the constraints of observation, and indeed of aesthetic, are mapped by many writers onto the acts of re-crafting in theatre, literature, visual arts or music. A nice example with an educational theme is given by Nichols and Stephens (2013).

Revisiting again, thanks to Huber, the 19th century forerunner of *PaMoS*, of Robert Hunt’s *The Poetry of Science*, we learn more. Science is poetical for Hunt, as Huber points out, not because it shares a comparable creative process, as I suggest in *PaMoS*, but because like poetry it can evoke senses of beauty, wonder and the sublime. Hunt, like Wordsworth, is careful to point out that this power is conditional, but unlike the poet this is not the social condition of a shared familiarity in feeling and suffering of the objects of science, but a qualitative requirement on its form. The aesthetic power of science is latent, for Hunt, in its induction of connective laws rather than the prior material of listed facts. Huber helps us to notice the same idea expressed in different ways by William Whewell’s ‘pearls on a string’ that connect observations by their underlying patterns, but by the time we hear Whewell’s description of this process the ‘imposition of formal unity’, not only are we far from Fuller’s ‘receptionist’ science and back to the manifest ‘expression’ of induction, but also I think meeting with a Romantic form of the ‘science as poetry’ metaphor. Science is never ‘read off’ nature, but ‘written into’ a picture, a narrative, or abstract constructed representation of it.

Barnie's personal account is rich in its articulation of another running metaphor for the creative process in poetry, which I think does bear resemblance to one path to ideation in science – that of fishing on a deep lake. Note that this is 'fly-fishing': the lure to attract poetic fragments remains on the visible (conscious) surface; they must swim up, unseen, to meet it. Some of those fragments were once formed from scientific ideas. I must quote the essential passage here:

Several decades on, however, I have internalised aspects of evolutionary biology and paleoanthropology to the extent that they become part of my mentality and bubble up from the place where poems are formed in the shape of images and themes without my having to think about them.

Comparing this with the passage from mathematician Henri Poincaré quoted in *PaMoS* (p.213):

I could not sleep; ideas rose in crowds; I felt them come against me until two of them were clinging to form a small combination. In the morning ... I had only to write the results, which took me a few hours.

Poincaré is telling Barnie that 'fly-fishing' lies very much within his experience of doing mathematics. Furthermore, the recurrent images of 'hidden depths' and the 'surfacing' of ideas speaks of the unconscious mind once again, and the need to place readings, experiences, and ideas there, however ill-formed and from however widely-scattered sources, if creative combinations are to surface weeks and even years later. Poetry, by its compositional practice of focused contemplation, reveals the experience of our subconscious creative realm more than any other art, and by that offers the practice of science a reflective model that illuminates, and might in future transform, our compositional processes as well.

Personal methodological and aesthetic comparison of poetry and science can perhaps be best testified to by those who are both scientists and poets. Very recently a (multi-) biographical study on this topic has been written by Sam Illingworth (2019), who draws our attention to the personally-felt connections to which his subjects can uniquely testify. Ada Lovelace, mathematician and daughter of Lord Byron, and herself a poet, writes of the 'white wings of imagination', when she thinks about science. She also confesses that her best personal preparation for composing poetry would be a week of mathematical work. Astronomer Rebecca Elson makes poems that reveal and articulate the inside of her science thinking and feeling in much the same way. The exemplars resonate with Barnie's personal account of the way that poetic ideas float up into his consciousness from an ocean-bottom he knows contains long-submerged and sunk concepts from science. But they float up partial and incomplete – another honest sharing that poet Ruth Padel observed (Padel 2011), commenting on her 2012 anthology *Mara Crossing*:

The deepest thing science and poetry share, perhaps, is the way they can tolerate uncertainty. They have a modesty in common: they do not have to say they're right. True, perhaps. Or just truer: "A scientist should be the first to say he doesn't know," a tiger biologist told me when I asked some detail of tiger behaviour. "A scientist goes forward towards truth but never gets there."

To end the incompleteness that this section must live with, I am delighted to report that, since publication of the book, I have received several unsolicited offerings of recently-published science-inspired poetry. Some are very good indeed, among them the Californian Mary Peelan's *Quantum Heresies* (2019) and the English North-Easterner Katrina Porteous' *Edge* (2019). These are poets who have dived deep into the science they write about, and made their home with the communities of scientists who listen, observe and imagine. Strikingly, both also adopt a powerful minimalist form. In Porteous' case the collaborations extended to musician Peter Zinovieff, whose music forms part of the poems' public performances. The role poetry plays within the larger work of sharing science as well as conceiving it is articulated in her introduction to *Edge*:

So these poems have an epistemological element: they are not just about what we know, but about how we know. The relation between scientific empiricism and poetic idealism fascinates me. In each case, I found myself writing my way towards a crude understanding of the subject, just as I would if I were grappling with a difficult human experience. The struggle to understand was also the effort to

forge a language in which to interrogate the subject. Since understanding was never more than proximate, the aim of each piece is not to convey accurate scientific information, but rather to translate the experience of trying to understand. As in any poem, my intention is not to explain anything, only to evoke some things. Much of this is achieved through metaphor, and through the physicality of sound.

I believe that in such effort of engagement, labour (which is necessary as much to the poet as to the scientist) we hear an answer to Wordsworth's (1802) call for science-inspired poetry,

The remotest discoveries of the Chemist, the Botanist, or Mineralogist, will be as proper objects of the Poet's art as any upon which it can be employed, if the time should ever come when these things shall be familiar to us, and the relations under which they are contemplated by the followers of these respective sciences shall be manifestly and palpably material to us as enjoying and suffering beings.

It is the haptic, immersed, visualised, sensed and heard qualities of the material world that, when responded to between poles of suffering and joy of the human condition, become the science of poetry.

Differences in the Creative and Imaginative Process of Art and Science

If my goal was originally to swim against the tide of prevalent narrative – that there is no 'creativity' in science – and if I attempted to do this by emphasising similarities between art and science (though I never, as some readers extrapolate, claim that they are 'identical'), then it is not surprising that another common thread in the responses is a cry to respect the differences. I think here that Zon provides a helpful framing of 'translation' and 'interpretation' for what I was trying to do. I don't know if I succeeded, but I recognised on reading his review the degree to which 'translating' between the accounts of artists and scientists, and 'interpreting' the one to the other, is more faithful to my project than notions of 'identity', 'similarity' or 'difference'. Furthermore, Zon's introduction of Walter Pater's notion of *anderstreben* extends the idea that science and art can 'seek the other', not to establish a static framework of comparison, but more to sustain a dialogue between their projects (or 'kingdoms' as Barnie would term them), much as do the science-informed poets Quinn and Porteous.

I have already responded to Fuller's charge that I see science as 'receptive', and can even agree with him that both art and science find commonality in the 'godlike' human empowerment to 'generate our own creations'. I cannot agree, however, that the resolution of 'reception' versus 'expression' is a binary one in either art or science, so as Fuller anticipates, I also disagree with Kuhn (1969) on his analysis of difference. Art does not have to be explicitly representational in order to respond to received stimulus, or to the potential connectivity between others' ideas. Likewise science neither relies entirely on deduction from external observations nor bears the interpretation of data-free projection onto the world. Furthermore, were Kuhn correct, we would expect continuous dispute over the meaning and definition of art (why should pure 'expression' of internal creations be beholden to any external convention), while steady agreement on the constitution of science (if externally defined there is no room for individual negotiation of territory). Although there has indeed been a running discussion on what does, and does not, count as art (e.g. Carey 2006), there is even now a fierce debate on whether untestable theories in theoretical high energy physics (such as 'string theory') ought to be admitted as 'science' (Hossenfelder 2018). One of the most serious criticisms of Kuhn's (1966) theory of 'paradigm revolutions' was provoked and witnessed by earlier instantiations of just this experience of contradictory paradigms running alongside each other (Masterman 1970). There is, however, a difference of degree at work here. The fulcrum which balances the 'extramission' of generation and the 'intromission' of reception, and the degree to which the resulting progeny are representational of the world, is admittedly, and by convention, placed at different points in art and science.

This variation seems, however, to be as large within the arts and sciences themselves: some sciences at are highly speculative and even deliberately counter-factual. The widely different degree of deployment of counter-factuals has been identified as a fundamental methodological divergence between physics and biology, for example (Poon 2006). This distinction is coloured, however, by the degree to which these two sciences are differently balanced between experimental and theoretical approaches in the implied activity of creative art and science. Zon directs our reflections away from abstract, conceptual and nominative thinking towards the grammar of the verbal – he recalls Chris Small’s active and participative definition of ‘musicking’ and wishes that it were possible ‘to science’. But author and screenplay writer Andy Weir (2015) has anticipated him: in the film version of *The Martian*, astronaut Mark Watney, inadvertently abandoned on Mars, declares to his empty otherworldly home that in the face of overwhelming odds, he is going to ‘science the shit out of this’. There follows an intense sequence of coordinated creative thought and activity that directs plant biology, atmospheric chemistry and astrophysics to the purpose of human survival on an alien world. The scene is almost balletic.

Both art and science call on haptic and manual facility as well as the conceptual and cognitive, but in different ways and to different degrees. An experimental physicist may spend considerable time arranging optical components on a vibration-free table, or a biologist delicately manipulating fluorescently labelled components in a cell. A theoretician is more likely to be engaging in the delicate interplay of conceptual models and their mathematical representation, loosely-coupled (at least at first) to the constraints of acquired data. As great a difference separates a theatrical director working with a cast of actors in rehearsal, and a composer working on a symphonic score. Here the request to distinguish with a lot more care the different meanings of ‘imagination’ and ‘creativity’, by Whitworth, is very helpful. The historical analysis in his survey is fascinating. Here I think that a brief consideration of the disparate activities required in the complete process of bringing works of art or science into being relegates ‘imagination’ to a part of the totality of a process of ‘creation’. Creativity manifests in a shared, outward, artefactual product, while ‘imagination’ refers to the inward and mental. As in the *Martian*, it is the choreographing of the two, once more the meeting of the extramissive and intramissive, the coordination of expression and reception, that conceives the creative act in totality.

There are other axes of difference along which the reviews seek to place art and science at different places; indeed just listing them suggests (to a mildly mathematical mind) a multidimensional analysis of their relation. The forgoing has very briefly considered those of interpretation-translation, expression-reception, contemplative-active and extramissive-intramissive. Other contrasts suggested by reviewers include the historical, social and institutional framings that constitute other sections of this response, but further dimensions raised, that might also be topics for future discussion, include the axis of individual-team labour (see brief discussion in the next section), subconscious-conscious activity, temporary-lasting value of their products (Barnie speaks to this), the degree to which aesthetics play out in creative process, and the extent of overlap of medium and message (Fuller, Barnie and Hugill). The last was responded to very briefly above under ‘Poetry’, but is a fascinating question that ought to attract a great deal more analysis that I am equipped to give.

Social and Institutional Framings of Science and Art

We must, however, think a little more about social framings. There is clear crossover between this set of topics and issues in the history of science, but when social and institutional structures and norms play out more strongly, we move the disciplinary focus of discussion into sociology, politics and ‘science and technology studies’, as well as the wider ‘history and philosophy of science’. Here is the place where we need to call on Popper, Kuhn, Feyerabend, Lakatos and the late 20th century story of the story of science. As a point of personal clarification, I have indeed read these authors (some reviewers assume otherwise for unstated reasons) – and, perhaps unusually – I really have no idea how many scientists read even the very elementary philosophy of science canon – made a point of doing so early in my professional scientific research career. I was very curious to discover how people thought science worked at that point (and of course still am), and also guessed that the years’ experience ‘on the inside’

might provide me with a critical store of data against which to assess those who attempt to describe the process from the outside. So Kuhn's *The Structure of Scientific Revolutions* has been a companion volume to me (although *Comments on the Relations of Science and Art* has not – for which many thanks to Fuller for drawing our attention to his perspective on the Two Culture's poles).

Some of the discussion of differences in science and art have been discussed above, but here I need to complete the work of correcting the impression Fuller has that I believe that both are about 'representation', rather than 'expression'. Indeed my whole thesis is that 'creativity' in science draws from the 'expressive' propensities and energies of human engagement with materiality. The metaphor of vision is apposite once more (*PaMoS* chapter 3) – neither intromission nor extramission alone will do, but the combination of the two. We project in science as much as we receive, and seek to explore meetings, even the most fleeting and ephemeral ones, between expression and impression. 'Representation' surely emerges from the meeting of these duals. So, although art and science, and essentially their products, are doubtless institutionally framed in different ways, I do not see that to categorise one as expressive (purely) and the other as representational (purely) is faithful to the experience of their communities of practice, nor that they constitute a proper pair of opposites. My *Leitmotif* of 'creativity with constraint' serves to underline the point. Scientific theories are *expressed* not sketched in charcoal from a clear vision of material reality, though they are constrained by a desire to represent in most cases (but even this is not true in the case of physics' penchant for the invention of alternative universes), guided by *impressions* of observation or experiment. Again, the long theological history of ideas provides a background to the scientific/artistic meeting of the external and internal – following the epistemological shift from Augustine to Aquinas as a transition from revelation to rationality. One reason that Grosseteste interests me so much is that his thinking seems to draw on a balance between such internal and external sources of imagination that breaks rather effectively late modern and exclusive dualisms such as Fuller's proposal.

The dualistic framing of internal and external carries the discussion to a related duality within the social framing of science – namely between individual and community. Given the recurrent imputation of the world 'hero' in the reviews (when the word does not arise at all in *PaMoS*), I need to be clearer than I was there on where I stand in respect of the 'great man' narrative of science: I do not subscribe to it. I had hoped that the drawing on as many 'small stories' (including my own) as those recorded by familiar names, would have made the point, especially when those narratives, in so far as they are personally known to me rather than merely edited into books, expose the communal character of science and the relational structures of its energies and imagination. I do quote some historical sources at length, but that does not imply that I am writing hagiographically. Re-tweeting does not imply endorsement. Beveridge, for example, is by no means my 'hero'. I include a summary account of his *Art of Scientific Investigation*, not because I adhere or even agree with all, or even with much, of it, but because it is significant that he deliberately writes in the genre of *Ars Poetica*, and as deliberately aims to resonate with respond to Henry James *Art of the Novel*. The topic of that chapter is the entangled story of the novel and scientific experiment.

Once the science-heroes are heaved down from their unwarranted pedestals (a Sisyphean, but necessary, task for historians of science) and the dust settles, the theatre is then cleared for a proper discussion of communally-held and developed narratives of science within communities of practice. Here is where Lakatos' 'programmes' resonate more faithfully with me than either of Kuhn's 'normal' or 'revolutionary' dynamics, and Fuller is right to recognise, as Kuhn did not, the repeated multiple coexistence of framings, as well as the multiple uses of 'paradigm' in his book (Margaret Masterman 1970, counted twenty-one!). Again, I am not proposing to advance a philosophy of science, rather to recognise, from within the community that creates it, what meta-narratives seem faithful to my experience, and which not, especially in regard to the experience of imagination. The scientific imagination is held, and extended, communally as much as it is internalised. Of all my early readings, the one that I recall being most energised and convinced by was Feyerabend's *Against Method*. After 30 years of professional science, I am still more inclined to the description that 'anything goes' as more faithful to the experience of method in the scientific community's changing notions of materiality, life and cosmos than any conjectures, refutations, programmes, or paradigm shifts. Leach writes of the

‘creativity of human social life’, which resonates with Feyerabend’s social generation of ideas, and especially of the way that social sub-communities within science can keep an idea alive through the period of gestation where strict Popperian rationalism would have demanded its abandonment. Communities both generate and sustain science, and more, are allowed and supported. Huber’s Wordsworthian notion of the ‘hard labour’ in science (as opposed to the ‘contemplative idleness’ of other creative activities) also speaks of a labouring community among which new ideas may surface in the communal conversation, rather than fully-formed in the mind of a single individual. I have experienced many examples of this route to ideation.

In terms of the *institutional* framing of science and art, again, important and even politically anguished though this is, such differences are not central to my purpose in *PaMoS* except in so far as they bear on the creative process. The creation of art or science is, however, not unconnected with their financial support, and the increasing instrumentalization reflected in current (at least UK national) science funding policy has the doubly-vicious consequence of tipping resources into science and technology and away from the arts and humanities, while at the same time requiring a twisted narrative, on behalf of those requesting funding, of a methodological project plan that conceals the uncontrollable and unmanageable in ideation and imagination. Creativity occurs, by this false and imposed narrative, on a scientific production line. I have elsewhere written of our modern grant-writing Scheherazades (McLeish 2014). The historical evolution of ‘imagination’ and ‘creativity’ that Whitworth tracks in the 20th century emergence of ‘R&D culture’ is fascinating in this regard, for the shift of a publicly perceived value in ‘creativity’ from disciplines like history and literary criticism to science and technology (as in McGurl and Kerr) points to an underlying shift in value, but also in the meaning of ‘creativity’ itself. One result is that some commercial operations now find it advantageous to annex the word, becoming the ‘creative industries’.

An implied but unarticulated consequence of *PaMoS*’s cry for a recognition that creativity plays a central role in science is that its institutional framing recognise this in evaluation, resourcing and formation. Fortunately this consequence has recently been developed much further by Lehmann and Gaskins (2019), who suggest that artistic practice provide a ‘template’ for a more explicit and structural consideration in science. Their proposal includes the transposition of artistic forms of heuristic practice, trial-and-error, self-critique, openness to accident, and environmental construction. While I think that these authors might underestimate the extent to which such practices already find a home in scientific research, their radical propositions for institutional support of art-science co-practice (including, on close reading, building explicit scientific contexts for the ‘fly-fishing’ of the poet that Bernie testifies to) that goes beyond the flimsy and superficial ‘sci-art’ to the generation of imaginative energy, is a welcome challenge.

Computing and Digital Creativity

Hugill takes me to task for my omission of any discussion of the digital realm and its already highly-developed role in artistic creativity, and especially in music. I have no defence but lack of expertise and knowledge, though one might rightly point out that that problem doesn’t seem to have prevented my writing about much else besides. I think his world might be a little coloured by the computational environment in which he himself works: to declare that ‘physics is almost entirely computational’ speaks more of that bias than of a knowledge of the current landscape of physics. Without diminishing the enormous power and application of computational simulation of matter on all scales, of the frontier topic of quantum computing, or of the advanced experimental instrumentation that it permits, computers remain a tool that physics deploys, not a dominant qualifier of the discipline. I think that Hugill might have fallen into the same categorisation error (that I, at least, claim) as Fuller between the expressive and receptive in science. In physics computation is expressive – these are instantiations of our model, imagined worlds, not microscopes conveying information from the external one. Before she simulates or computes, a physicist conceives the question, idea, algorithm. To be sure, the interaction of the searching human mind with the programme and its output is a part of the continuous process of

creativity, but I am not sure that this is not one of degree, rather than kind, when compared to the traditional and historical technologies of art and science (but see the discussion above, motivated by Hugill and also missing from *PaMoS*). Hugill himself writes of computers that ‘paint beautiful paintings and make marvellous music, and people must find ways to negotiate relationships with the machines they themselves have created’, but the creation of the paintings and music is as implicit in the creation of the machines as it is in the wonderful artisanal account of shaping and drilling the oboe?

A recent discussion that might suggest a direction to take Hugill’s helpful critique is Marcus du Sautoy’s *Creativity Code* (du Sautoy 2019). Du Sautoy, a professional mathematician and also serious amateur musician, considers in depth the current algorithms that generate art, music and even mathematics. Throughout, his account sustains the tension of the underlying question of digital creativity: are the machines creators in the same sense that human beings are, or are they our tools in creativity, however sophisticated those tools might be. In regard to music, he concludes, ‘despite the fact that these algorithms appear to have cracked the musical code, there is nothing stirring inside the machine. These are still our tools, the modern-day digital bullroarers.’ And on narrative journeys, ‘computers will be the telescopes and typewriters, not the storytellers.’ This is all in spite of seriously impressive accounts of computer-generated film-score music, sports commentary, and of course the celebrated innovations of DeepMind in the game of Go. Du Sautoy concludes with a brief discussion of the activity of deliberate choice, sense of self, and consciousness. These are, of course, the central questions raised by Artificial Intelligence, within which the topic of creativity must remain both central and urgent.

Theological Tropes in Creativity

Any serious discussion, in the late modern west, of as deeply held a human values, and as long a history, as creativity is bound to draw on theological material, and to excite theological resonance. Not only *PaMoS* itself, but many of the reviewers’ responses testify to that expectation. The book (and the précis prepared for this collection) reflects on the creative implication of the *imago dei* tradition, the ancient nature-wisdom tradition of *Job*, and the analytical tools for teleology that theology as a discipline provides. Barnie presents us with a myriad of angels, Fuller writes of the cultural divide as a ‘second fall’, Leach of transcendence, Huber of the glory and truth of divine creation and the tradition of ‘natural theology’, Whitworth informs us that the earliest citation of ‘creativity’ in the OED refers to divine activity, and Zon’s review is trinitarian and hypostatic throughout in its theme of ‘music-theology’. Although much of this material has fuelled discussion in the forgoing sections, here we draw some of its themes and questions together.

To begin with it is worth recalling perhaps the primary historical creative leap from theological to scientific ideas: that the imagination to overcome the obstacles to experimental method drew its vision and energy from theological sources is now established (e.g. Harrison 2007). Whether the Christian concept of Fall and Redemption simply solves a problem of its own making (as Leach would have it) is not my concern here, but serves to shed some early-modern contextual light on the points I was trying to make under *The End of Creativity* (*PaMoS* p.323), and on the creative process in general. It is surely not only the secularism of our age that renders Harrison’s findings so strange to our ears, but principally the disciplinary fragmentation since then, that objects to the idea that theological ideas could build a conceptual bridge over a scientific chasm from the artificiality of experiment to the subtleties of nature (as Margaret Cavendish argued). Yet Harrison writes (quoting Glanville’s 1661 *Vanity of Dogmatism*), ‘Experimental philosophy ... was thus fitly described as a philosophy “that becomes the sons of Adam”’ (Harrison 2007, p.67). The point is not only that theological narratives are as suitable a source of interdisciplinary ideation as any other of the humanities’ disciplines, but that there are certain structures, we might without minimising call them *aesthetic* (in the sense of Poincaré’s subconscious filter), that speak to the negotiation of relationship between the human and non-human. It is in this light remarkable that Zon directs our attention to the hypostatic union of the Trinity as a ‘template for trying to understand the nature and meaning of relationships – relationships between numbers, between

musical notes, between words, between disciplines, between science and the arts – between what something is, and what something represents in the totality of its meaning.’

Relationships, their making, breaking and healing, their fruitfulness and progeny, conscious and unconscious, lie at the heart of creation and creativity of all kinds. It is tempting to suggest that, irrespective of whether the categories of our thinking had inherited a centuries-long theological tradition or not, we would be inventing one to provide the nourishment from which this discussion has palpably drawn. If Fuller is correct that the tragic divorce of arts and sciences constitutes a ‘Second Fall’, if Barnie is right to call on poetry, and Huber’s insight that it is poetry’s theological locus that witnessed the parting of ways on target, if Whitworth’s emphasis on historical awareness and Zon’s hypostasis a worthy object of contemplation in the task, then perhaps a ‘Second Coming’ in poetic form, and in the mystical company of Yeats, is the appropriate and apophatic place to pause, and to reflect, for now (*The Second Coming*, Yeats 1921)

*Turning and turning in the widening gyre
The falcon cannot hear the falconer;
Things fall apart; the centre cannot hold;
Mere anarchy is loosed upon the world,
The blood-dimmed tide is loosed, and everywhere
The ceremony of innocence is drowned;
The best lack all conviction, while the worst
Are full of passionate intensity.*

*Surely some revelation is at hand;
Surely the Second Coming is at hand.
The Second Coming! Hardly are those words out
When a vast image out of Spiritus Mundi
Troubles my sight: somewhere in sands of the desert
A shape with lion body and the head of a man,
A gaze blank and pitiless as the sun,
Is moving its slow thighs, while all about it
Reel shadows of the indignant desert birds.
The darkness drops again; but now I know
That twenty centuries of stony sleep
Were vexed to nightmare by a rocking cradle,
And what rough beast, its hour come round at last,
Slouches towards Bethlehem to be born?*

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