

Uncertain Encounters: Traversing Life, Biology and Modern Genomics

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DECLARATION

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I hereby declare that the research embodied in the present dissertation entitled, '**Uncertain Encounters: Traversing Life, Biology and Modern Genomics**' is carried out under the supervision of **Prof. Sasheej Hegde**, Department of Sociology, School of Social Sciences, University of Hyderabad, Hyderabad, for the award of Master of Philosophy, is an original work of mine and to the best of my knowledge no part of this dissertation has been submitted for the award of any research degree or diploma at any university. I also declare that this is a bonafide research work which is free from plagiarism. I hereby agree that my dissertation can be deposited in Shodhganga/INFLIBNET.

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This is to certify that **Samiksha Bhan** (Reg. No. 17SSHL09) has carried out the research work in the present dissertation entitled, '**Uncertain Encounters: Traversing Life, Biology and Modern Genomics**' in partial fulfilment of the requirements for the award of the degree of Master of Philosophy in Sociology, under the supervision of **Prof. Sasheej Hegde**, in Department of Sociology of University of Hyderabad. This dissertation is an independent work and has not been submitted for the award of any degree of this or any other University.

Further, the student has passed the following coursework requirement for the M.Phil:

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Chapter 1



By Way of Introduction: Inside/Outside Biology and Modern Genomics

New knowledge must perforce discredit old knowledge. Knowing very well why we want new knowledge, we should not be surprised at the uncertainty that is generated (Douglas 1990: 11-12).

On 3rd June 2016, the already renowned World Science Festival which had launched itself in New York in 2008, held a panel discussion titled ‘Genome Engineering and the CRISPR Revolution’ as part of its annual festival.¹ The discussion was preceded by a video informing the public about what it meant to ‘engineer’ genomes, the totality of genetic material in an organism’s cell, what this new technique represented that allowed scientists to edit genomes, about how it can potentially change the face of research in genetics and biomedicine and how it could be a way for scientists to achieve in a short time what had taken years in the processes of evolution. CRISPR (which stands for ‘Clustered Regularly Interspaced Short Palindromic Repeats’) is the newest in a series of technologies that enable gene editing at a speed previously unimaginable by biologists in the laboratory.

Interestingly, before being identified as a tool for gene editing, CRISPR had been recognised as short DNA sequences that exist within the cells of most bacteria as part of their auto-immune system to fight against viral attacks. With technologies of reading whole genomes and penetrating into the molecular structure of organisms, scientists had realised that the bacterial world at large employs this immune system, especially when viruses attack and take host on their genetic make-up, as a mechanism through which

¹ The events recounted from here were accessible through the video of the proceedings that was uploaded on YouTube (see ‘Splicing and Dicing DNA: Genome Engineering and the CRISPR Revolution’ <https://www.youtube.com/watch?v=Nimj6SNPq-ov>). Last accessed 31 March 2019.

they identify the viral DNA, replicate it in the form of RNA and employ a protein called ‘Cas 9’ to cut the infected DNA sequence at a precise location. Multiple versions of this mechanism called CRISPR were developed in the labs of biochemists and molecular biologists in some of the leading universities of the world, using different kinds of bacteria as their base samples. Existing in the natural world and thus becoming a problem for ownership as a scientific product, a version of the technique termed as the ‘CRISPR-Cas 9 system’ was founded by two biochemists in 2012, working jointly from the University of California, Berkeley and the Max Planck research institution in Germany, who then sought a patent for establishing the use of this technique for targeted gene editing. The CRISPR-Cas 9 system, it is claimed, allows for a faster, cheaper and more accurate method for ‘splicing and dicing’ of genes in various organisms including humans. The seemingly unlimited possibilities of this technique is said to have introduced a new paradigm in biological research, even constituting a ‘revolution’ of sorts. One could potentially cure diseases with strong genetic links like cancer and Huntington’s, but one could also ‘optimise’ human characteristics such as intelligence and height.

The World Science Festival describes its mission as “cultivating a general public informed by science, inspired by its wonder, convinced of its value, and prepared to engage with its implications for the future”.² The panel discussion thus acquired a tone of engagement with the public, fleshing out a complex scientific phenomenon in layman terms, with the linguistic register of scientists constantly depending on colloquial analogies to explain the technical aspects of the procedure. The members on the panel included a molecular biologist working at a gene editing company, a professor of pathology and paediatrics, a post-doctoral researcher working on virus-carrying mosquitoes, a professor of biochemistry and medicine, a professor of genetics at Harvard Medical School, and an expert on bioethics, all bound by their use and opinions on this new breakthrough technology. Thus, covering a vast array of stakeholders within the world of biology and biomedicine, the discussion was intended to raise pertinent issues

² See the official website of the World Science Festival for the description (<https://www.worldsciencefestival.com/about/>). Last accessed 31 March 2019.

about the potential benefits and dangers involved in changing our very genetic constitution. Needless to say, the questions raised to the panellists all revolved around the implications of this ‘engineering’ for both human and non-human forms of life: in particular, the possibilities of using CRISPR as a technique to eliminate malaria or the zika virus by editing the genes of mosquitoes; its effect on the debate around genetically modified foods in terms of increasing agricultural productivity for the growing world population, while also accounting for the hazards of consuming that kind of food; the ethical implications and possible public backlash of editing genes in human embryos; the possibility of backtracking from a new technology in the light of its potential misuse; the conditions of a robust regulatory mechanism for a technology such as CRISPR; and, finally, the characteristics of a world revolutionised by gene editing. In other words, the modalities of this questioning can be succinctly posed as “what does a CRISPR-ised world look like?” Indeed, to formulate this question in both scientific and socio-political terms, we must ask: what does the world of accessible technologies of life as foregrounded in the turn to genomics entail?

The ‘Brave New World’ of Modern Genomics: Thinking with Uncertainty

A simple search on Google Scholars shows about more than 6000 entries under the keywords ‘brave new world’ and ‘genomics’ put together. Not surprisingly, expert scientific commentary on genome editing has often taken on an oracular voice announcing the advent of a new world untamed, and yet not totally adrift, full of all the contradictory possibilities that the future holds. The emotions of excitement and caution play out equally and often simultaneously in narratives of experts involved in the brave new field of genome sequencing, mapping and engineering. There is excitement for reasons of creating opportunities for better health, to make a world less surrounded by death and disease. To be sure, if one can change the naturally imperfect state of organisms as most commonly affected by diseases that are inherited, one can make for a world surrounded by less suffering. Equally, as well, there are alarms of caution and fear, based on the fact that possessing the key to altering life also means holding the power of granting and taking away life - the capacity really of what Michel Foucault

(1978) had famously proclaimed as ‘making live and letting die’ - and thus forming a temporality of living oscillating between granting birth and pronouncing death. One can, of course, say that birth and death were always uncertain in some sense. What may be specific of the ‘brave new world’ of genomics is that it has made all aspects of life fall in the space of uncertainty.

Without doubt, a major source of this uncertainty stems from digital technologies capable of storing and translating vast amounts of genomic data. Today, the knowledges of life and their corresponding technological apparatuses are first and foremost being produced within biology and the space of the contemporary life sciences. Most conclusively, the panoply of technologies of life that are available today owe a great deal of their conceptual and technical know-how to cellular and molecular mechanisms that have been unravelled within genetics and molecular biology since the 20th century. The two events that are of crucial importance to this history are the elucidation of the structure of DNA in the 1950s and the launch of the Human Genome Project (HGP) in the 1990s. If the former established the textuality of DNA as a 4-letter code that binds all life forms on earth and accordingly carries the ‘information of life’, the latter (namely, HGP) sought to make the whole genome of a human being known to all, while also inquiring into the variations and the ‘normal’ behaviour of genes and making these new insights available to medical use (see Mukherjee 2016: 14). Together these sciences of life that form the basis of the ‘new biology’ are intersecting each other, compounded by the fact of increases in computing power and other forms of technological prowess. Needless to say, what was seen as science fiction a decade ago is translating into concrete visions of our present and ongoing reality.

Exemplary future-oriented research is being undertaken at present at Calico, a biomedical company funded by Google that seeks to solve the ‘problem of death’ by studying ageing and life-extension.³ Another favourite science fiction vision was made into a reality in the ‘cloning’ of Dolly, the sheep, in 1996 by the Scottish scientist Ian Wilmut and his

³ See ‘How Google’s Calico aims to fight aging and ‘solve death’, <https://edition.cnn.com/2013/10/03/tech/innovation/google-calico-aging-death/>. Last accessed 31 March 2019.

team using stem cell technology (see overall Franklin 2005). Even more recently, in December 2018, the birth of the Chinese twins from embryos whose genomes were edited through CRISPR against the genetic inheritance for the HIV disease which one of the parents carried, has ushered us into another science fiction-like contemporary world of genetically modified humans.⁴ These events have altered the face of contemporary science and the larger society, raising fundamental epistemological questions like how to classify organisms-with-modifications in the various current taxonomies of science, as also deeper ethical questions about how to take responsibility for our biological and social futures and even whether humanity can indulge in such techno-scientific dreams when the available resources and forms of scientific attention can be diverted to basic biological research and healthcare.

At any rate, the reflective cancer physician and researcher Siddhartha Mukherjee sums up the historical significance of modern genomics when he adroitly states that the three “profoundly destabilising ideas” running through the 20th century are those of the atom, the byte and the gene, which together make the fundamental units of physics, computer science and biology respectively (see Mukherjee 2016: 10-13). Even as these fundamental entities may have been known (or, better still, hypothesised) before, the 20th century became the time when they were operationalised in a sociological and technological realm and thus served to destabilise not only previously held scientific knowledge but also social ideas: the atom through the powers of destruction of life as generated by the atomic bomb, the byte through its redistribution of the powers of communication, and the gene through its power to permanently change the course of all organic life. Without doubt, in our ongoing 21st century, the very space of biology and the life sciences as a whole are beginning to play a critical role in redefining how we think about life, make use of living matter as technology and overall learn about how to lead a good life. No wonder then that at least some bioethicists have suggested that a technique like CRISPR can be classified as ‘disruptive technologies’ that potentially

⁴ See ‘A Chinese scientist says he edited babies’ genes. What are the rights of the genetically modified child? (https://www.washingtonpost.com/news/monkey-cage/wp/2018/12/06/a-chinese-scientist-says-hes-edited-babies-genes-what-are-the-rights-of-the-genetically-modified-child/?noredirect=on&utm_term=.cd8bbace96fb). Last accessed 31 March 2019.

transform an entire field of study, changing existing relations, practices and modes of production as well as social institutions and moral domains of life (see Greenfield et al. 2016: 18). If both the concept and techniques of the gene have destabilised existing scientific and social practices in the contemporary world, constituting as it were a sort of ‘genomics revolution’, what are the frames from within which we can track the dimensions of this change – indeed account for it in historically epistemic terms while also cognizing the shape of its uncertain futures?⁵ The present study is a preliminary undertaking to get a measure of this profound question.

Some Further Theoretical Moves and Research Manoeuvrings

In the light of the background just laid out, our study will dwell on three main problem areas as embodied in the chronology of the following three chapters (as sequentially rendered in the course of this dissertation): **(A)** How did life come to be conceptualised, analysed and intervened upon at the molecular level in the vestiges of Western thought and science (broadly the basis of Ch.2)?; **(B)** What were the epistemological conditions within the discipline of biology that shifted its unit of analysis from organisms to genes and the genome, and eventually drew the limits of that reduction in understanding life (Ch.3 broadly)?; and **(C)** What kinds of political, ethical and technological problems arise as modern genomics comes to participate in biomedical regimes governing the lives of people (the basis of Ch.4)? Questions **(A)** and **(B)** belong largely to the domain of knowledge-production, with the first of our substantive chapters (Ch.2) inquiring largely into conceptualisations of life in philosophy, science, and the vitalist politics of the times and the subsequent chapter (Ch.3) recalling in fuller terms a trajectory within the conceptual and methodological domains of disciplinary biology. The penultimate chapter (namely, Ch.4), in keeping with the thrust of question **(C)**, will largely be concerned with the sociological and anthropological aspects that assume significance as the contemporary field of genomics becomes entrenched in individual and collective forms of life.

⁵ On the very nature and consequences of the ‘genomic regime’ – with the phrase ‘genomics revolution’ prominently positioned - see Hilgartner (2017).

Science as Historical Knowledge

Since our study has majorly to do with the knowledge of such concepts as life, genes and genomes as they feature in science, we should give some weight to the historical processes and practices of science that bring these concepts into being. Historians of science Hans-Jorg Rheinberger (2000 and 2010) and Lorraine Daston (2000) have contributed in their different ways to thinking about how histories of science can be written that are also devoted to epistemological questions (see Feest and Sturm 2011). Inevitably, this line of work has meant approaching science as a practice of knowledge-making that is historically mediated. Setting the stage for such efforts under the broad rubric of ‘historical epistemology’ – itself inspired by the creative oeuvre of the French philosopher of science and medicine, Georges Canguilhem (see 1994 and 2008 [1966]) - Rheinberger claims that in the transition from the 19th to 20th century sciences, the understanding of epistemology changed from being a mere theory of knowledge to “reflecting on the historical conditions under which, and the means with which, things are made into objects of knowledge” (Rheinberger 2010: 2). For Rheinberger, this change was characteristic of a transformation in the very problem space of epistemology that had gone from conceptualising the object of science from the perspective of the knowing subject to reflecting on “the relationship between object and concept that started from the object to be known” (ibid.: 3). Indeed, the increasingly experimental mould within which the sciences come to be practiced since the 19th century becomes the driving force behind an endeavour such as historical epistemology, as it came to be realised that there can be no knowing of the object in transcendental terms and, even more so, that the object itself had to be grasped under historically variable conditions.

On similar lines, Daston (2000) proposes to approach ‘scientific objects’ as both real and historical objects. Her critique is set against the backdrop of such oppositional positions as realism and constructionism adopted by sociologists, historians and philosophers of science in analysing scientific questions. While realists see scientific objects as “discoveries, unexplored territory waiting to be mapped” (see Daston 2000: 2), constructionists regard these objects as inventions or fabrications that are strictly tied to

a specific time and place, in the process denying them their reality in favour of historicity. Both these positions, as Daston also urges, lose their feasibility for a comprehensive analysis of science as historical knowledge. Her simple and yet concrete suggestion is that to grasp how scientific objects come into being, sustain their presence and pass away (in some instances), one needs deeper engagements with both the real and the historical. This necessarily entails recognising that the phenomenon in question has a reality before it becomes a scientific object, even as scientific inquiry per se stabilises the same or classifies it into a coherent category (ibid.: 6). It also involves recognising that scientific objects are not inert but produce results in the form of applications, techniques, or explanations (ibid.: 10); and, what is more, they are also embedded in the larger domains of scientific culture that includes instruments, like microscopes, and non-human model organisms that are used in research (ibid.: 12). Following these guidelines, in the course of our narration across Chs.2-3 primarily, we foreground the historically mediated knowledge practices that made life, biology and modern genomics come into existence.

Contingent formations and the idiom of co-production

Apart from dwelling in the spaces of knowledge from which scientific objects emerge, our study also tries to raise the question of how we as human beings relate to ourselves, to others and to the multiple worlds that we contingently inhabit. The anthropologist-theorist Paul Rabinow frames this as the fundamental problem when he urges that there are no unifying discourses or concepts that define the figure of ‘anthropos’. For him, the recent developments in the sciences of life and communicative technologies have rendered it even more glaring that multiple discourses are being assembled in contingent formations (see Rabinow 2003: 15). Indeed, even as the unifying concepts of the gene and genome were undercut by the increasingly experimental knowledge of molecular biology (as our Chs.3-4 will disclose), it is only an ‘anthropology of the contemporary’ in the expansive terms urged by Rabinow that can precisely describe such contingent formations that human beings are increasingly becoming a part and parcel of.

Another band of anthropologists, as anchored by Stephen Collier and Aihwa Ong (2005), propose the concept of ‘global assemblages’ to refer to the products of contemporary

science and technology that are global and yet locally mediated in specific contexts. Within the framework of this understanding, the HGP can become one such site of a ‘global assemblage’ involving scientists, medical practitioners and other publics of multiple countries, which made universalising claims like ‘reading the book of life’ (see Rose 2007: 45) and/or the genome as belonging to “every member of the human race” (see Palsson 2007: 154) while it was very clear that the genomes sequenced were in all likelihood those of the inhabitants of the U.S. (incidentally, the spearhead of the project). Capturing the contingency of such formations, Collier and Ong define assemblages as “the product of multiple determinations that are not reducible to a single logic”, while going on to urge: “The temporality of an assemblage is emergent. It does not always involve new forms, but forms that are shifting, in formation, or at stake” (Collier and Ong 2005: 12). Such contingent formations, as the authors’ further propose, can be assessed by reflecting on the technological aspect, political form and ethical questions of value that global assemblages put into motion. We specifically focus on some of these dimensions of modern genomics as it bears on contemporary biomedicine in Ch.4.

The landscapes of modern genomics also present us with the challenge of thematising formations that emerge at the intersections of science, technology, law, politics, industry, health and the always already established field of social identities. In this sense, the products of science and technology can hardly be examined from any one dominant disciplinary perspective. This is the broad line of critique which the science and technology studies (STS) scholar Sheila Jasanoff provides in forwarding the idiom of ‘co-production’ of the scientific and the social world. For Jasanoff, the dominant conceptual frameworks of sociology, economics or even political science lack the vocabulary to make sense of the “untidy, uneven processes through which the production of science and technology gets entangled with social norms and hierarchies ... and change(s) the very terms in which human beings think of themselves and their position in the world” (Jasanoff 2004: 2). She proposes the ‘idiom’ of co-production, as opposed to a full-fledged theory with predictive power, to describe complex sociotechnical formations in terms other than those of either technological or social determinism (ibid.: 3). More importantly for our purposes, Jasanoff underscores that the idiom of ‘co-

production’ can also form the basis of a dialogue between historical and contemporary science and technology as temporality is not a “pre-ordained conceptual and methodological barrier for analysis in STS” (ibid.). While explicitly using this idiom in Ch.4, the idea yet yields a binding thread that runs across the manifold contours of our study, placing in perspective the inseparability of scientific and social life.

A Note on Sources

For a dissertation that limits itself to an engaged review of the secondary literature on the conceptual spaces of life, biology and modern genomics, we have found our way through works traversing various disciplines such as the philosophy and history of science and biology in particular, anthropology and sociology, including the occasional scientific report as available on the internet. With texts from the history of science dominating our bibliography, it is not surprising that our analysis has been biased towards the intellectual histories of science, biology and genetics while recounting specific empirical contexts. All the same, the contours of our tracking has also included critical commentaries by social scientists - sociological, ethnographic as well as historical - documenting the emergence and effects of the modern biological sciences and genomic technologies in particular. Powering our narrative is also literature produced by scientists themselves, coming from specialisations in theoretical physics, biology, medicine, physiology, evolutionary and molecular biology, each of whom have simultaneously written on the history and philosophy of science. Online sources for a topic that is as controversial as it is new inevitably leads to accessing web journals on science, including the official websites of the National Institutes of Health (NIH), National Human Genome Research Institute (NHGRI), National Centre for Biotechnological Information (NCBI), each of which provided the scientific impulse for some background research on the topic.

Chapter 2



Life and the Sciences: An Initial Determination

Life is the formation of forms. Knowledge is the analysis of in-formed matter. It is normal that an analysis could never explain a formation and that one loses sight of the originality of forms when one sees them only as results whose causes or components are to be determined (Canguilhem 2008 [1966]: xix).

Today we have discovered a powerful and elegant way to understand the universe, a method called science; it has revealed to us a universe so ancient and so vast that human affairs seem at first sight to be of little consequence. We have grown distant from the Cosmos. It has seemed remote and irrelevant to everyday concerns. But science has found not only that the universe has a reeling and ecstatic grandeur, not only that it is accessible to human understanding, but also that we are, in a very real and profound sense, a part of that Cosmos, born from it, our fate deeply connected with it (Sagan 1980: 2).

This chapter recounts the relationship between life and the sciences, that is to say, how the sciences have historically understood the concept of life. The aim of undertaking this history is to contextualize how the human condition reached the contemporary state of affairs that historians and sociologists have recognised as ‘the molecular vision to life’ (Kay 1993; Rose 2007). The question of life can be transposed onto many different planes of explanation. Philosophy, insofar as we acknowledge has to do with thought per se, holds some authority on questions raised historically about the nature and meaning of life. However, as disciplines have developed over the ages, so have their problems and questions. Science as a formal discipline as well as a practical activity is born out of philosophy itself. The much contested problem of what life is, how it entered the domain of science and society, and what are the dominant approaches in the history of science that characterize the problem of life will be the jurisdiction of this chapter. It will also lay the groundwork for the dissertation ahead as it goes on to explore the sites of life, biology and modern genomics and their interrelationship.

To enter into the conceptual field that life refers to, one needs to start at some elementary level of reflecting on the word itself and its etymology. The *Oxford English Dictionary* (*OED*) consists of multiple entries on the word ‘life’, broadly classified under four headings:

1. The condition that distinguishes animals and plants from inorganic matter, including the capacity for growth, reproduction, functional activity, and continual change preceding death.
2. The existence of an individual human being or animal.
3. (Usually one’s life) the period between the birth and death of a living thing, especially a human being.
4. Vitality, vigour, or energy (*OED*).

One will notice, as we move along this chapter, how the four meanings are at some points implicated in various explanations of the concept. As seems implicit in its origin, life foregrounds a kind of reflexivity, something that one could have given a name to by way of reflection. A philosophizing move seems to be at play and thus the reflection of most philosophers of ancient civilizations, from the West as well as the East, on the question of what the meaning of life is and what its determining aspects are (as also how one can lead a good life). At the same time, life also seems immediate and spontaneous, that is, involving an action that is not necessarily mediated. The life of an organism can be simply defined as its interaction with its environment, and an organism attempts to do so because that is only the way to live. Of course, the term ‘organism’ enters the discourse on life only after modern biology establishes itself as a ‘science of the living’ (see Mayr 1997), as we shall broadly recount in the next chapter. Prior to the making of formal systems of knowledge or disciplines, life was thought of as an intrinsically cohesive subject, something that needed to be made known.

For the word ‘science’, interestingly, the *OED* gives a much shorter entry, describing it as “the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment”. What distinguishes science from any other “intellectual or practical activity” is its nature of being a *systematic* study that involves observation and

experiment. This is the standard definition that is transmitted through elementary textbooks of science. However, while studying about the great names of the world of classical science, like Aristotle or Copernicus or even Aryabhata, we realise that these personalities were not called ‘scientists’. This is because these thinkers were deliberating about the structure and behaviour of the natural world prior to the birth of modern science. Science today is a much more formalised system. Regardless, even today to do science is to know more about the world in which we live. Knowledge is what described the quest and motivation of all science from its earliest manifestations as ‘natural philosophy’.

I. Locating Life: Intersections of Philosophy and Science

All the great classical thinkers from most parts of the world were philosophers of nature in the quest of knowing the world around them, and through that knowing their place in the world. In the revised preface to his English book *‘The Logic of Scientific Discovery’* (2002 [1959]), Karl Popper notes that there is at least one philosophical problem that attracts the curiosity of all thinking beings, and that is the problem of cosmology. He famously declares that all science is cosmology, insofar as we understand that all science grew out of philosophy. The problems of philosophy, and thus of science, are precisely *“the problem of understanding the world - including ourselves and our knowledge, as part of the world”* (Popper 2002 [1959]: xviii, emphasis in original).

The word ‘cosmos’ holds an important place for its meaning and implication in the context of the history of science. Originating in Greek, ‘cosmos’ refers to the order of the universe, meaning that there is a certain design regulating our world, which as we will see was the driving force to discover and construct the laws of nature. What it implies, as Carl Sagan so accurately put forth, is “the deep interconnectedness of all things ... convey[ing] awe for the intricate and subtle way in which the universe is put together” (Sagan 1980: 16). The word also helps us to understand how the question of life was staged in much broader theatres of knowledge and reflection, and how it came to be narrowed down to ‘organisms’ in the modern discipline of biology.

Life in Antiquity: Western Lineages

The question of how to understand the world and in the process understand oneself is perhaps as old as the earliest human settlements and reflection. One can speculate that it was indeed a sense of awe for the intricacies of nature that led the earliest humans to become curious about how the world operates. In the opening chapter of the book titled '*A History of the Life Sciences*' (2002), the historian of biology Lois N. Magner traces the origin of biological thought back to the Neolithic age when modern humans had become domesticated and the mode of food production changed from hunting and gathering to reliance on farming and animal husbandry. Magner speaks through an anthropological lens when she points out that what distinguished Homo Sapiens from the hunter-gatherer communities of the Palaeolithic era was the use of "fire, speech, abstract thought, religion and magic" (Magner 2002: 2). The development of tools and systems of thought thus become, in her account, an immediate impetus to think about fundamental questions of life - "birth and death, health and disease, pain and hunger" (ibid.).

Undoubtedly, the earliest natural philosophers were interested in the question of how life came to be created and regulated in the cosmos. Magner notes that natural science was born not in sixth century Athens as is popularly believed, but travelled to Greece from the fringes of Asia Minor known as Ionia (Magner 2002: 10).¹ The natural philosophers of the city of Miletus constructed cosmological theories establishing natural elements as the raw material for the creation of the universe. In fact, Thales who is considered to be the founder of Ionian philosophy suggested that the world could be explained in purely naturalistic terms. There was disagreement, however, on what were the primary elements and forces that shaped the cosmos (ibid.).² The composition of the universe was a way

¹ Moving away from the Eurocentric assumption that the invention of science is solely to the credit of natural philosophers who lived in sixth century Greece, Magner also draws out brief histories of documented and formal systems of science of life from the civilisations of China, India, Mesopotamia and Egypt. Ancient writings in Chinese Taoism, the textually documented history of Ayurveda as a science of life developed in India, and the Mesopotamian myths on the cosmological significance of the earth and water, all had a quality of classifying objects in the environment on the basis of vital properties.

² Thales, for example, believed water to be the fundamental element from which all things and beings took shape. Anaximander is popular for having formulated the theory of four elements - earth, water, fire and air - that made up the world, to have thought of motion and origin of earth by giving an account of the

of understanding the constitution of all beings in the world; and it is not surprising that the idea that all elements in the world are made of atoms was experimentally verified by John Dalton only at the beginning of the nineteenth century. However, the word ‘atom’, like ‘cosmos’ came from ancient Greek and the postulate that the world is composed of ‘indivisible units’ moving through infinite void in space existed among the fifth century Ionian philosophers most popularly associated with the name of Democritus. Within this ancient theory, it is important to note that the mechanical interaction between atoms and the void (or empty space) held the possibility of innumerable worlds.³

By observing phenomena in everyday life experience, the Greeks of the pre-Socratic era were on a quest to understand and control nature, giving birth to a ‘natural philosophy’ that meditated on everything from the elements that made up the cosmos to the motion of the earth, from a theoretical model of atoms to the famous medical theory of humoral elements that governed the body. There soon grew a Hippocratic school of medicine, named after its founding practitioner Hippocrates (460-361 BC), as part of the ancient academy, which postulated that the human body was made up of four cardinal fluids called ‘humours’ - blood, black bile, yellow bile and phlegm - and that disease was caused by an imbalance of the same (see Mukherjee 2011: 48). This theory made it possible to think about death and disease in materialist terms, taking it out of the realm of religion or metaphysics. More importantly, it defined what it meant to lead a good and healthy life up until the birth of modern physiology.

Interestingly, the medical theory was also an intermediate requirement for the pre-scientific physiology of organisms to be developed from the Pythagorean transmigration of souls to Aristotle’s levels of organisation of the soul (see Simondon 2012: 32-36). To elaborate from Simondon, the soul in the transmigration model moves on a horizontal

vortex, and by theorising that change is what drives the cosmic cycle from chaos to order (see Magner 2002: 11-13).

³ The *Stanford Encyclopaedia of Philosophy* explains the theory of multiple worlds given by Democritus in the following manner: “Clusters of atoms moving in the infinite void come to form *kosmoi* or worlds as a result of a circular motion that gathers atoms up into a whirl; creating clusters within it these *kosmoi* are impermanent. Our world and the species within it have arisen from the collision of atoms moving about in such a whirl, and will likewise disintegrate in time” (Source: <https://plato.stanford.edu/entries/democritus/>).

plane, without differentiating between a ‘simple’ and ‘complex’ being or an animate or inanimate being. The soul is taken to be commensurable and migrates from any one entity to another. However, the soul in the Aristotelian paradigm is organised on a vertical axis, where the level of organisation of a particular entity classifies the type of soul. The soul is no longer commensurable but is characteristic of an entity’s internal nature. Indeed, this turn to bodies and souls in the natural philosophy of Western antiquity leads to the question of what exactly determined the condition of life in individual beings. By way of answer: it was the soul and its function in the body that was understood to keep the body alive. In fact, since antiquity, it was the awareness of a vital principle that drew a line of distinction between the living and non-living through discussions on the soul (see Simondon 2012: 32). The soul came to separate the animate from the inanimate. Life was identified with the soul and the soul in turn was identified with breath. Indeed, presenting breath as the underlying existence of vitality was an anthropomorphic definition of life (see Canguilhem 1994: 74-75).

However, there were other underlying principles for defining vitality as discussed in Simondon’s (2012) account of demarcations of living beings and their behaviour drawn since antiquity. Explicitly, he makes use of psychological concepts of instinct and intelligence in the historical understanding of animal life that bears on some fundamental notions in the natural and human sciences (including the notion of life) [see Simondon 2012: 31]. Instinct is often characterised as a lower function, while intelligence is understood as something that exists in more sophisticated beings. Indeed, for the pre-Socratic philosophers there was no distinction between instinct and intelligence; all that existed was plant life, animal life, and human life (ibid.: 32). It was with Socrates that this belief in continuity of life was disturbed marking an “anthropological difference” between man and the rest of the living beings (ibid.: 10). Establishing a kind of humanism, Socrates had effectively argued that man possessed intelligence, while animals and plants possessed only instinct (ibid.: 36-37).

All the same, according to Canguilhem, we find the first general definition of life in Aristotle: “Of natural bodies (that is, those not fabricated by man) some possess vitality,

others do not. We mean by ‘possessing vitality’ that a thing can nourish itself and grow and decay” (as quoted in Canguilhem 1994: 67). More insistently, elaborating on the importance of Aristotle in the history of life, Canguilhem notes:

If Greek philosophers prior to Aristotle, especially Plato, speculated about the essence and destiny of the soul, it was Aristotle’s *De Anima* that first proposed the traditional distinction between the vegetative or nutritive soul, the faculty of growth and reproduction; the animal or sensitive soul, the faculty to feel, desire and move; and the reasonable or thinking soul, the faculty of humanity (Canguilhem 1994: 74).

The soul, accordingly, existed in all living beings, but took on different forms and levels of organisation. Indeed, in predating the formal taxonomic exercises of the seventeenth and eighteenth centuries, Aristotle classified living beings on the basis of their structure and mode of reproduction, with the ascending grade of life forms being classified as going from vegetal to the animate to the human, and finally to immortals or gods. Simondon sharply notes that “Aristotle’s oeuvre is essentially a work of biology and natural history [...] in developing the notion of function, in flushing out the different vital drives of the notion of function”, which rendered species comparable through the notion of life (Simondon 2012: 50). In other words, Aristotle took account of the invariance across all living beings through the invariance of life: that life poses the same demands everywhere “in an oyster, in a tree, in an animal, or in a man” (ibid.: 51) but the form of meeting those demands changes with the change in the structure and behaviour of the being.

Mechanistic Explanations of Life

The idea of vitality, as we shall look more closely in the next section, was crucial in laying out how the sciences understood life. Vitalism in essence posed and attempted to explain life in opposition to mechanism. If vitalism was fundamentally based on a monism (that is, the belief that all living beings were united by a vital life force), then mechanism was fundamentally tied to a dualism, mostly in terms of the distinction between mind and body (see Lash 2006: 324). Palpably, mechanistic explanations of life also shaped themselves by opposing vitalism’s position that there was a vital force or energy governing life. Indeed, Cartesian thought, which itself stands at the cusp of

medieval philosophy and modern science, became the most popular system of thought that represented this dualism.⁴

Scholars have recounted that the birth of modern science was set in motion with the work of Copernicus published in 1543 who gave a heliocentric view of the cosmos refuting against the ‘geocentrism’ of the Ancients (see Hellyer 2008; Mayr 1997). It is widely accepted that the Copernican revolution was what allowed for breakthroughs in the study of planetary motion laid down by Galileo and Kepler and consolidated as what came to be known as classical mechanics in Newton’s *Principia* published in 1687. Broadly, mathematical models to understand the motion of heavenly bodies provided a way to know the ‘mechanics’ of the world rather than thinking about how the world was in a metaphysical manner. The late medieval and early Renaissance period in most parts of Europe was undergoing what came to be known as the ‘Scientific Revolution’ where new discoveries were bringing forth fresh perspectives on understanding life (see Hellyer 2008).

More pointedly, the biologist and historian of science Ernst Mayr (1997) highlights that mechanics was the first science to develop coherent laws and methods, even maintaining the rise of mechanism as a way of thinking constitutive of the Scientific Revolution itself. The scientific mind had to purge itself from any kind of unreasonably religious or metaphysical thinking that theories of Antiquity or Middle Ages indulged by means of recourse to the soul. However, given the rise of Christianity in the medieval period, as Mayr elucidates, the architects of the Scientific Revolution failed to revolt against fundamental Christian beliefs. Modern science thus inherited an ideological bias towards

⁴We say ‘most popular’ because, as Simondon (2012) points out, with Socrates the first attempt to establish a duality in nature was put in place by suggesting a separation between animal reality and human reality. This project was taken forward by his disciple Plato who laid out three orders of animate existence - reason, heart (or ‘elan’) and desire - of which the human possessed all three. With Plato, says Simondon, we also get the first theory of evolution, only a reverse one: from Man evolved the rest of the beings in the world. Between the doctrines of antiquity and Cartesianism of the 17th century, there were also the religious teachings of early Christian scholars that posited animal life in opposition to human life, rendering the animal devoid of feeling or reflection (in essence, devoid of a soul). However, by going through the history that Simondon lays out, it becomes clear that no neat demarcation can be made by way of corresponding patterns of belief with a distinct time period. Just as dualistic doctrines of Socrates, Plato and the Stoics existed in antiquity, doctrines of monism and aspects of vitalism existed in the Renaissance.

Christianity and worked to find the mechanisms of the Divine Law. The latter, obviously, had to be universal, and not chaotic in its essence. Accordingly, if life had to be explained in a scientific manner in the 17th century, be it at the level of the cosmos or the individual being, it had to have foundational laws governing it and a systematic language that could express it. Indeed, such a rationale puts into perspective why Galileo had famously remarked after mathematically proving Kepler's laws of planetary motion that he had discovered the language in which God created life. Or even why Descartes, as an icon of 17th century physiology, declared all beings except for the human as nothing but automata.⁵

Modern science around the 17th century clearly came to be bound by ideals of certainty. It became imperative to ask how one knows what one knows; in other words, science became concerned with epistemology as a theory of knowledge. Historians of science have reconstructed how the history of epistemology coincided and co-evolved with the history of the sciences (see Daston 2005; Rheinberger 2010). Modern science had arisen from the conception that formal knowledge needs to justify its methods. Indeed, in keeping with this understanding, epistemology can be defined as the study of the justification of belief by means of evaluating if the evidence meets the demands of a belief (see Daston 2005: 4).⁶ The modern sciences were understood to be equipped with much stronger epistemological tools like the telescope and microscope that set them apart from the cosmological speculations of the natural philosophers of antiquity (ibid.: 5). Accordingly, where philosophers of antiquity used speculation and observation as their tools, modern scientists had invented and foregrounded the importance of

⁵ Within the Cartesian theory of *cogito ergo sum*, the mind serves the function of judgement and was ordained directly by God. Descartes assumed animals to be incapable of language and invention and thus of judgement. The mechanisation of the animal soul thus completed the 'mechanisation of the world picture' that began with the construction of physical laws of nature in the formation of disciplinary physics (see Mayr 1997: 3-4).

⁶ As part of this understanding, Daston traces the contested and ever-changing relationship between what counts as knowledge and what is dismissed as mere belief or conjecture in the history of scientific practice. But, of course, epistemology itself signifies a much larger domain in science and philosophy. Another historian of science, Hans-Jörg Rheinberger defines epistemology as understood in the French tradition as reflection "on the historical conditions under which, and the means with which, things are made into objects of knowledge" (Rheinberger 2010: 2).

experimentation (ibid.: 18). Evidently, in such a context, the epistemological basis of explaining life was expected to be both exact and certain.

However, some grand questions loomed large in the face of this assumed certainty. Cognitive scientist and philosopher Daniel Dennett (1995), following Aristotle, reminds us that curiosity about anything can be framed in the form of four causes. Drawing on Aristotle's oeuvre, the causes are framed as: (a) *material cause*, or what is the matter that makes up a thing? (b) *formal cause*, or what is the form (structure or shape) of that matter? (c) *efficient cause*, or what was its point of beginning? (d) *final cause*, or what is the purpose, goal or end of that particular thing? (see Dennett 1995: 23). In thinking about life, these ultimate causes posed the problem of answering about the material, form, origin and design that life itself consisted in (ibid.). Indeed, these were the grand questions that occupied the space of intersection between philosophy and science. More directly, yet, the birth of biology in the 19th century had changed the course of the way many scientists answered these fundamental questions. The most important breakthrough, in this context, was made by the influence of evolutionary theory in explaining a common origin of species by focusing on the material and formal aspects of life. In fact, before Darwin (1809-1882), species were considered to be immutable and timeless; in other words, the knowledge of how one form developed from another was entirely missing. What evolutionary theory foregrounded was a common descent of species uniting all life forms in a 'Tree of Life', the latter constituting "that representational branching structure that Charles Darwin advanced as a grid for organizing knowledge about the history of life on Earth" (Helmreich 2011: 685).

Darwin's enterprise was clearly a grand theory of the 'mechanism' of life (see Dennett 1995), but a mechanism different from Cartesian dualism. The former's evolution by natural selection, by no means, solved all questions of material, form, origin, and design. It did not, for instance, solve the problem of abiogenesis, which as some physicists believe cannot possibly be explained through mechanical laws (see Davies 1999).⁷ But

⁷ Abiogenesis, as rendered within the scope of the ongoing discussion, raises the problem of origins of life (that is, how life came to exist from non-life). Darwin's invocation of the 'Tree of Life' had traced all life on earth to a common ancestor, but it did not postulate any theory regarding the very origin of life. Thus,

it did provide a strong explanation for the development of life. Thus, as Dennett reminds, along with launching a severe attack on the predominant belief in creationism, the nineteenth century witnessed that “in a single stroke the idea of evolution by natural selection unifies the realm of life, meaning and purpose with the realm of space and time, cause and effect, mechanism and physical law” (Dennett 1995: 21). In its epistemological articulation, Darwin had moved away from mere descriptive analysis of life and living beings as articulated in the framework of classical taxonomy devised by natural historians (see broadly Foucault 2002 [1970]; more on this in the following chapter of our dissertation) to a mechanical explanation, posing a challenge to metaphysical invocations of soul or vital ‘life force’.

Within such a matrix of explanation, what articulated vitality in living beings was a ‘material form’ rather than a ‘life force’ (see Helmreich and Roosth 2010: 37).⁸ This material form, as opposed to the seventeenth-century Cartesian mechanism, had relocated the proliferation of life in the relation between an individual being and its environment, a relation of survival through adaptation common across life forms. Thus, while Descartes reserved the faculty of a mind or a soul to the human exclusively, Darwin placed the human in line with other species taking account of the physiological similarity that existed in all living beings.

Life as Organisation and the Organisation of Life

As is well-documented, Darwin’s evolution by natural selection explained life as the interaction between a mechanism embedded in nature and the individual organism’s ability to adapt to its environment. The mechanism in nature was termed as ‘natural

as Dennett wryly remarks: “Controversy about the mechanisms and principles of speciation still persists, so in one sense neither Darwin nor any subsequent Darwinian has explained the origin of species” (Dennett 1995: 44).

⁸ In taking cognizance of Darwin’s usage of ‘life forms’ as giving importance to *material form* rather than a *life force*, Helmreich and Roosth further stress that for Darwin “life forms were not expressions of an abstract archetype and certainly not emergent from an internal teleological force; rather any such archetype as there might be was a material ancestor” (Helmreich and Roosth 2010: 37). They point to how Darwin uses the idea of a material form of life to ‘inductively (though speculatively)’ give an answer to the problem of biogenesis: “In *Origins*, Darwin writes of the ‘general succession in the forms of life’. At the end of the first edition of *Origins*, though, he writes that ‘probably all the organic beings which have ever lived on this earth have descended from some primordial form, into which life was first breathed’, a phrasing that permits readers to imagine material form as separate from a life force” (ibid.: 37-38).

selection’ by him, and this mechanism acted as a “sculptor of form” (Helmreich and Roosth 2010: 34). The word ‘form’ used in such a biological sense can either refer to that which emerges with ‘embodiment’ or as something that acts as a ‘tool of classification’. In the nineteenth century, the two meanings of form combined together to deliberate about “how an organism’s morphology might be affected by its surrounding environment and about how this might in turn guide possible classificatory systems.” (ibid: 30). The metaphor of the ‘tree of life’ that Darwin used for evolution signifies such an interconnection in the meaning of form when it brings together the form of the individual organism in the same diagram as the organisation of species into a branching structure.

More pointedly, this hierarchy of species was in turn based on understandings of life as self-organisation. In fact, Evelyn Fox Keller (2005) has recounted that the terms ‘organism’ and ‘self-organisation’ used in relation to living beings were first popularised in Kant’s theory of aesthetic judgement of forms, and accordingly goes on to describe the ‘organism’ as “a bounded body capable not only of self-regulation and self-steering but also, and perhaps most important, of self-formation and self-generation” (Keller 2005: 1070). Indeed for Kant (as Keller reminds): “the concept of self-organization liberates living creatures from the necessity for a designer. No external force, no divine architect, is responsible for the organization of nature, only the internal dynamics of the being itself” (ibid.).

Emphatically, tracing further the etymology of ‘organism’, she points out that it is this internal dynamics conceptualised in the principle of self-organisation that separates the meaning of the word from its Greek roots as ‘*organon*’, meaning a tool. A tool, as opposed to a self-organised being, requires a user (ibid.: 1069). In Kant, thus, this internal dynamics that is responsible for the organisation of life in nature also provokes an understanding of *life as organisation*. Indeed, as Keller surmises, Kant postulated that the mechanism of this internal dynamics could not be answered by pre-existing sciences and needed an entirely new science for its study. Accordingly, at the dawn of the 19th

century, the term ‘self-organisation’ came to define the fundamental question of the life sciences, that is, the question of how to define an organism (ibid.: 1070).⁹

Such an understanding of life was further enabled by concepts introduced in the study of nineteenth century physiology as exemplified in the works of Claude Bernard (1813-1878), who foregrounded the use of life as organisation by posing the constitutive question, in what sense is an organism organised (see Canguilhem 1994: esp. 261-84, as also 67-90 *passim*). In this theory of general physiology, the object of study is the interaction between the organism and the milieu, with the living body itself being seen to be composed of a chemical structure (what Bernard termed the ‘inner milieu’) and a morphology (its external form or milieu). Broadly, ancient science, up until the introduction of anatomy and physiology, had prioritised (as was claimed by Bernard) the study of external milieu alone, whereas it was Bernard’s contention that the experimental view of life as organisation would require an equal emphasis on the ‘inner milieu’, which as created by the organism itself is taken as special to every living being (see Canguilhem 2008 [1966]: 7).

Indeed, in Bernard’s conception, the workings of an organ must be approached as a physicochemical phenomenon, even as a functioning organism was seen as one engaged in its own destruction (see Canguilhem 1994: 67-90 *passim*). Life was accordingly conceptualised as a gradual movement towards death, and thus possessing the tendency to slow down entropy. Similar views had been held by earlier physicians and naturalists who approached the body as a ‘composite whole’. For instance, George Ernst Stahl (1660-1734), a German physician, emphasised the need for a theory of life as a “necessary prerequisite to medical thought and practice” and emphasised that living beings are composite bodies with the “power [to] temporarily suspend a destiny of

⁹ The use of the term ‘biology’ for the first time is credited to Gottfried Reinhold Treviranus and Jean Baptiste Lamarck in 1802, a few years after Kant’s *Critique of Judgement* was published in 1790. The specificity of biology came with the specificity of nature for Kant (that is, the ability in nature to organise by means of internal causation). Keller (2005) astutely reminds us that for Kant and his contemporaries the new science of the living had to be irreducible to the existing sciences of physics and chemistry. This distinction between biology and physical sciences came to be more and more reduced with the birth of molecular biology, as will be covered in the next chapter of our dissertation.

corruptibility” (see Canguilhem 1994: 68-69). In fact, in Stahl’s overall thesis, the body was composed of “small corpuscles” as well as an “aggregated state” (Stollberg nd: 3). An aggregated state that is the sum of parts was not reducible to physical laws, and could only be explained by a ‘living principle’ which in his (Stahl) near-animist theory was translated as the soul (ibid.). Consequently, death was a state of chemical decay; and, not surprisingly, such a conception of life as organisation also triggered thinking about the relationship between conditions of health and disease (or the concepts of normal and the pathological).¹⁰ Undeniably, for Bernard, disease was placed at the intersection of the internal and external milieu, which altogether made the experimental physiologist incapable of approaching it as a generalised entity (see further Normandin 2007).

More specifically, opening up to the relation between an internal and external state of the living body was mediated by what Nikolas Rose has called an “epistemology of depth” (Rose 2007: 42). This epistemology, as practiced in the sciences of the 18th and 19th centuries, is laid down in the works of Michel Foucault. In *The Order of Things* (2002 [1970]), Foucault traced how the taxonomy of the ‘Classical Age’ that categorized each plant or animal into a genus or species was reformulated by installing the division of two kingdoms in nature, the organic and the inorganic. This was the ‘depth’ that opened up beneath the taxonomic table, as Rose urges, based on an understanding of what constituted vitality. This new knowledge, besides, also informed a shift within medicine that Foucault addresses through changes in French medical thought in his *The Birth of the Clinic* (2003 [1963]), wherein proponents of the emerging medical sciences had come to define life as a set of functions that can resist death and disease as a result of altered functions. This mutated definition of life and death reoriented the pre-existing medicine of surfaces and classifications that hitherto arranged diseases according to their distinct symptoms. Medicine, accordingly, came to analyse organs and functions at the level of

¹⁰ Interestingly, the idea of the body as an ‘aggregated state’ can also be found to travel to the social sciences through Auguste Comte who defined the organism as a “consensus of functions in regular and permanent association with a collection of other functions” (see Canguilhem 1994: 83). Canguilhem even credits that it was Comte’s “biological philosophy that set forth [at the beginning of nineteenth century] in systematic fashion the elements of a theory of living organisation” (ibid.). As is generally known, Comte was famous for terming sociology as ‘social physics’, but his notion of society as an organism that comes into formation through consensus took its inspiration from the physiological theories of his time.

the individual body (see Rose 2007: 43), thus shifting the gaze to what Bernard had called the ‘inner milieu’ of every living being.

A completely new episteme or space of knowledge had opened as the experimental sciences became equipped with this “epistemology of depth”, one that had begun to focus on the internal workings of the organism. Foucault had famously declared that before this epistemological rupture ‘life itself’ did not exist. But, more poignantly, life in its moment of inception as an object of analysis became inadvertently lodged into death, while at the same time it was also a movement opposing death (see Rose 2007: 42). Indeed, life and death could be understood as two modes of life itself because “the form of a living body is more essential than its matter, since the latter changes constantly while the former is preserved” (Cuvier 1810, as quoted in Canguilhem 1994: 70). It then becomes imperative to ask what characterises the form of life, if both organic and inorganic are different forms of matter. For Bernard, the form of the living organism was characterised by a constancy whose mechanism he termed as ‘internal secretion’, which (as Canguilhem reminds) comes to be known as ‘homeostasis’ or the state of equilibrium central to the ‘modern conception of living organization’ (see Canguilhem 1994: 85).

Keller (2008) sharply recounts that in the latter half of the 19th century, terms like ‘equilibrium’, ‘stability’ and ‘fixity’ became popular in both the physical and life sciences to establish defining traits of all systems, as also the specificity of living systems. In fact, the vocabulary of ‘systems’ developed precisely to think about what governs organisation in any conglomeration, and specifically to think of the similarity and differences between an organism and a machine. Indeed, as Keller (2008) has noted, if both organism and machine as conglomerations are organised somehow or the other, then the burden of difference falls on the term ‘self’. It is not surprising therefore that *self*-organisation and *self*-regulation as unique to living systems was a maxim widely accepted till the beginning decades of the twentieth century. It was only in the 1920s and 1930s that a distinction was drawn between ‘equilibrium’ as understood in physics (and more specifically, thermodynamics) and ‘stable states’ as used in the logic of life sciences. It was from the physical sciences that it was postulated that the structure and organization

of “life machines” are not static, but rather in the state of dynamic equilibria, that is, always in process through interactions with their environment (ibid: 59). In short, organisation as a criterion of life opened a whole new field of possibility for interpreting and intervening into living systems, as will be addressed in the next section through the lens of vitalism.

II. Vitalism and the Novelty of Life

Any substantial investigation into the concept of life inevitably needs to glance through a history of vitalism. Vitalism as a form of thought takes us to the heart of fundamental questions about life that the previous section has flagged. To summarise, these questions are: what is life? How does the living differ from the non-living? What characterises the structure of the living? And, what philosophical and epistemological claims can be underlined by new understandings in science over the course of time? (see Normandin and Wolfe 2013). Not surprisingly, new ways of understanding and doing science in the 20th century have rendered both life and vitalism as conceptually and practically innovative fields of analysis.

Introducing Vitalism

Having carved out a brief history of the concept of life in the first section, we can notice that vitalism as a thought has been prevalent throughout in the doctrines of Western antiquity. References to soul and breath (‘anima’ and ‘animus’, respectively, in Aristotle’s work) best exemplify the way in which vitalism acted as an underlying principle without being invoked as such. Gunnar Stollberg simply defines vitalism as “a theory of life in the life sciences (natural philosophy, natural sciences, and medicine) that debates life in relation – not necessarily in opposition – to physics and physicalism, which reduces all life activities to physical phenomena” (Stollberg nd: 1). For Stollberg, vitalism can be traced in the history of life sciences in its three phases/concepts: animism, life force and an organising principle. These frames of thought - as we have briefly traced in the previous section (albeit not rendered as distinct phases) - dominated explanations of life until the twentieth century when vitalism as a scientific theory of life was rejected

by mainstream biology. However, the currency of vitalism goes beyond this conventional history as part of the life sciences, as we shall see.

The conflicting relation with physicalism is also a recent point in the history of vitalism. Accordingly, in its moment of consolidation following from the Scientific Revolution, vitalism grew as an anti-movement resolutely against physicalism or mechanism for explaining life (see Mayr 1997). In fact, in the introduction to their special number on ‘new vitalism’, Fraser et al. (2005) invoke Canguilhem (2008) to assert that the ‘vitality’ of vitalism is historical. Following Canguilhem, the authors’ reflect on how vitalism has acted as a negative term of reference, an error against which the history of biological thought has progressed. However, it continues to have a necessary and positive function to play, which is to pose a resistance to reduction at all levels. Setting aside the details of its history, we will briefly summarise some major ideas and approaches that scholars have associated with vitalism.

Some analytical concepts foundationally associated with vitalism that pose a challenge to reduction are that of flux, process, and relationality (see Fraser et al. 2005; Lash 2006; Normandin and Wolfe 2013). Vitalism, as Scott Lash pointedly notes, can be adopted as a theory of flux, as opposed to that of pure flow (see Lash 2006). Accordingly, if the idea of life can be conceptualised as “form (and experience) as well as knowledge of that form” (Canguilhem 1994: 19), then vitalism can be a useful approach to embed the tensions of flux that inhere in that experience and knowledge. A vitalist reading of life can thus never miss out on qualities of elasticity or plasticity that characterise life forms both in terms of how they are shaped by their environment as well as by each other (Helmreich and Roosth 2010: 34). Such a view would mean approaching living systems as essentially open and bringing into relation the study of individual development with that of how organisms relate to each other, rather than studying the individual and the group, the particular and the universal, at two distinct and separate levels. In the next chapter, we shall specifically note how the knowledge of the gene and heredity is able to bridge these various analytical levels.

For the moment, as indicated in our first section above, vitalism is considered to be philosophically monist as opposed to the dualism that characterises most forms of mechanism. It is 'monist' insofar as it rejects classificatory theories of knowledge that attempt to subsume the particular under the universal (Lash 2006: 324). In this sense, a vitalist perspective focuses on relationality between entities that are themselves considered to be open and distinct from each other. Focusing on relations, in fact, can be a starting point to challenge dualisms such as natural and artificial, while also tracing how they got constituted as dualisms in the first place (Fraser et al. 2005: 3).¹¹ The dichotomy between nature and artifice gets primarily challenged as part of the new sciences of life, as will be addressed in the following subsection. All the same, quite apart from problematizing concepts belonging to dualistic categories, relationality renders problematic the boundary between disciplines and the 'practicality' of their facts. It is held that all facts, from the natural or the human sciences, can be undone (or deconstructed) so as to bring to light their processes of constitution. This is made possible by what Fraser et al. call 'process thinking' in deference to Whitehead. Specifically, to think of process as an actual mode of being is to value the temporality of 'becoming' over that of 'being', or, in other words, to approach life as a vital process rather than as a static phenomenon.¹²

20th Century and Beyond: Cybernetics, Information and Life

To bring life, science and vitalism in an analytical relationship with each other, one cannot ignore the dramatic changes that have followed around the latter half of the twentieth century. To be sure, vitalism gained renewed currency in the light of new ideas of information, complexity and cybernetics (see Lash 2006). The boundaries between the living and non-living that had seemed solidified in the nineteenth century were

¹¹ The authors' specifically refer to thinkers such as Alfred N. Whitehead, Gilles Deleuze and Donna Haraway, each of whom are seen to utilise the notion of relationality in their very different conceptual apparatus so as to analyse how entities are constituted by relations with each other.

¹² On the different approaches to the concept of 'becoming', the authors' point out that a liberatory and ephemeral type of process thinking can be seen in theories of performativity coming from scholars of gender, mainly, Judith Butler. They accept that in performativity, there remains the sense of freedom and deconstruction that is associated with the concept of 'becoming'. However, it is pointed out that vitalist thinking is different from such theories because the former mode not only concentrates on a deconstruction of facts, but also a reconstruction of facts by drawing on their relationality (see Fraser et al. 2005).

problematized by the early decades of the twentieth century. Both historians of science Lily E. Kay (1997) and Evelyn Fox Keller (2008) have written about the mutating relationship between life and the sciences following from the Second World War. But, taking off from the concluding points of the first section, one would recount that a vital realignment between machine, organism and physicochemical systems had already been in play by the 1920s and 30s. Accordingly, even as the organism was being known in more and more ‘machinist’ ways, a simultaneous effort to know what made living systems unique was also at work within the sciences.

All the same, post-World War II Western scientific and technological efforts were driven to make organism-like machines inspired by and modelled after Bernard’s incipient concept of homeostasis and Kant’s purposiveness of form (see Keller 2008). Indeed, this was the moment when mathematician Norbert Wiener famously redefined the term ‘cybernetics’, formalising it as the science of “feedback, control and communication”, that is

a new science of the inanimate, a science based on principles of feedback and circular causality, and aimed at the mechanical implementation of exactly the kind of purposive organization of which Kant had written and that was so vividly exemplified by biological organisms; in other words, a science that would repudiate the very distinction between organism and machine on which the concept of self-organization was originally predicated (Keller 2008.: 65).

Cybernetics itself can thus be understood as a practice that stood at the interface of science and engineering. In fact, this was in line with the larger norms governing post-war science that had problematized the boundary between ‘pure science’ and applied technology. One of the most significant contributions of cybernetics was to bring together the organism and the machine into a relation of complete homology. It professed a rationality according to which all organisms were machines, and at least some machines could be made into organisms (Keller, *ibid.*), given the abiding definition of organisms at that historic juncture. Clearly, the matter and form that brought the organism and machine together at a fundamental level was ‘information’. Even more poignantly, this coming together of organism and machine is further recorded and celebrated in the terminology of the *cyb-org* that feminist scholar Donna Haraway adopts. She explicitly describes the cyborg as

a hybrid creature, composed of organism and machine. But, cyborgs are compounded of special kinds of machines and special kinds of organisms appropriate to the late twentieth century. Cyborgs are post-Second World War hybrid entities made of, first, ourselves and other organic creatures in our unchosen ‘high-technological’ guise as information systems, texts, and ergonomically controlled labouring, desiring, and reproducing systems. The second essential ingredient in cyborgs as machines is their guise, also, as communications systems, texts, and self-acting, ergonomically designed apparatuses (Haraway 1991: 11).

Indeed, as Kay insistently reminds, the separation of the organic and inorganic and the natural and the artificial was further problematised by the “discourse of information”, while drawing on Foucault’s archaeological strategies to open up a field of possibility for new objects and representations of nature to be probed (see Kay 1997). Information, in this sense, becomes a linguistic form of ‘dispersion’ whose particular modality as defined within cybernetics comes to enter into other domains. The information discourse is taken to mediate between the ‘intra-scientific’ and ‘extra-scientific’ realms, forming what Kay calls a “cultural semiotics” of science (ibid.: 30). Thus, from denoting an action of ‘in-forming’ through communication or knowledge, Kay concludes that information came to be used as a metaphor for other entities and forms of life.

In such a historical context, heredity became one of the key phenomena that came to be re-described in the terminology of information. Indeed, it can be affirmed that information was first and foremost used as a model and metaphor to understand and describe life. Following the discovery of the structure of DNA by Watson and Crick in 1954, Canguilhem had famously insinuated that the ‘language of life’ needs to be understood if life had to be decoded (see Rabinow 2006: 329; Rose 2007: 44). Contemporary biology increasingly had dropped the conventions of physics and chemistry and adopted the linguistic registers of information and communication theory (Rose, *ibid.*). In fact, the power of the informational metaphor can be seen not only in describing how life came to be conceptualised after the discovery of the genetic code, but also in the terms employed by evolutionary biology. Evidently, Dennett is thinking with the information paradigm when he says that Darwin’s “dangerous idea” had attempted to explain life as being acted out in an “algorithmic process that makes no use of a pre-existing Mind” (Dennett 1995: 83). Importantly, conceptualising this particular coupling

of life and information - especially as foregrounded in the Human Genome Project, to which we will allude in the subsequent chapters - many scholars have diagnosed a shift in the very epistemology of biology, with human and non-human life being approached at the molecular level.¹³

Significantly, in a historically motivated keyword entry of 'life forms', Helmreich and Roosth (2010) postulate that in the latter part of 20th century, life forms have come to denote a conjectural quality, occupying an uncertain realm of possibility that may or may not materialise in the future. Such an understanding, to be sure, would need to be further modulated by concepts and practices that separate 'life' from 'form'. In fact, specifically with this consideration in view, the authors' note that from the 1960s onwards, 'form' comes to be conceptually predictive due to the informational nature of the genetic code. Additionally, form becomes programmatic as well, specifically by way of a description of the mechanism that defined the structure. But, as Helmreich and Roosth declare, how could form be separated from any part of the organism that is not formed itself? Indeed, if life is a property of the organisation of matter, and not a property of matter per se, then it can be found and created anywhere (ibid.: 40). Such is the logic, precisely, behind fields like synthetic biology and artificial intelligence, the creation of life forms be it in the laboratory or generated on a computer. These developments embedded in the logic of life foreground that the relations between knowledge, science and information are open to contestations, both within the natural sciences and without (see Fraser et al. 2005).

Vital Processes in Social Life

As indicated in the previous sub-section, concepts that take birth within a particular science may not remain restricted to that science, given that they have gained enough ground in and as discourse. The concepts of life and vitality (or even vital process) are such that they are invoked in both individual and collective domains of life. For Canguilhem, specifically, questions of vitality were fundamentally normative questions

¹³ The following chapter will offer, in some detail, a historical epistemology of how the relationship between life and information gets established in the disciplinary space of biology through knowledge of the gene as a molecular entity, reorganising (as Rose 2007 has overall termed) the 'gaze of the life sciences' in assessing life, health and disease.

that human beings cannot ignore. By ‘normative’, Canguilhem only meant that the relation between an organism and its environment is not a pre-given condition, but is rather a situated practice through which any being learns to live in accordance with norms (see Canguilhem 1994: esp. 351-84). This means that the vital processes do not acquire a separate domain from social processes, since even within the latter we try to attain normativity in our relation with others. It is because of this simple and yet strong idea that the new vitalist thought has become fundamental to work within ‘the age of bioscience’. Indeed, Paul Rabinow, in his lucid introduction to Canguilhem’s work, cites this renewed significance of vitalism in approaching concepts of norm and life, death and information that are taking on centre stage in scientific and social arenas (see Rabinow 1994).

It is also for this reason that an attention to vital processes can help us in thinking of change in terms of both endurance and novelty at the same time, as Donna Haraway puts it (see Fraser et al. 2005). The discerning reader would have noticed that, up until this point in our chapter, our reference has either been to the generic concept of life or the life in terms of an individual organism. But life also took on a presence at an aggregated mass scale, perhaps for the first time, through the relationship between vital processes and the state. In fact, in discussing a historical relationship between life and politics, Nikolas Rose recalls Foucault’s account of biopolitics at the moment of the emergence of contemporary biological control and management (see Rose 2007: 52-54). In Foucault’s frame, at least since the 18th century, forms of collective and individual life became an object of management for the sovereign state. An expansion in jurisdiction of governance for the sovereign state meant that it not only had power over the life and death of its subjects - a right that was exercised by the previous disciplinary systems - but also exercised the power to ‘manage’ life at the micro level. These micro processes included practices of health, birth rate and sanitation, that is, practices of everyday life (see Foucault 1997).

This form of politics that Foucault termed as ‘biopolitics’ took into account the vital characteristics of human existence, that is the processes through which all “living

creatures are born, mature, inhabit a body that can be trained and augmented, and then sicken and die” (Rose 2007: 54). It is precisely these processes that made Canguilhem declare that life is a ‘normative activity’. Biopolitics then, in the way Foucault designed it, brings a vitalist character to the existence of individuals as political subjects, and is closely bound by the rise of the life sciences, human sciences and clinical medicine. Rose’s own argument is that one can do better by approaching it (biopolitics, that is) as a perspective rather than a concept, which brings into view novel practices of life in political, economic and technological spheres (ibid.).

Contemporary biosciences and technology in the practices they activate have brought the biopolitical dimension into a clearer view by producing not only neutral facts of knowledge but also values and judgements on the question of how one should live (see Fraser et al. 2005). In other words, the transition in the organisation of life - not quite at the level of individual, but collective – stemming from following a classificatory mode and attaining a quality of surveillance of micro practices, expresses a more immanent or vitalist logic (see Lash 2006: 325). Indeed, with this renewed currency of vitalist thought, it has been argued that determination of life as seen from the lens of evolution brought natural history and cultural history together, mediating between dualistic categories of nature and culture and mind and body (see Brown 2014: 331).

Following from such transitions 21st century scholars have argued that life and its control and management in the contemporary age signifies not the social control of biology, but rather an increase in ‘biologisation’ (see Rabinow 2006; Rose 2007; Landecker 2007). The contours of what this biologisation of society entailed especially in the realm of contemporary biomedicine will be discussed in our penultimate chapter (that is, Ch.4), after traversing a trajectory in biology that leads to the ‘genomics revolution’ in contemporary life sciences.

Chapter 3



Organisms, Genes and the Genome: Charting a Trajectory in Biology

When the Same and the Other both belong to a single space, there is natural history; something like biology becomes possible when this unity of level begins to break up, and when differences stand out against the background of an identity that is deeper and as it were, more serious, than that unity (Foucault 2002 [1970]: 288-89).

The contemporary empirical sciences, especially the life sciences, are founded on experimental systems, a special kind of assemblage for the production of knowledge. From time to time, and usually through the coincidence of incremental decisions rather than on the basis of deliberate revisions, conjunctures occur in or between such systems that from then on not only let things appear in a new light, but also let them happen in a different way (Muller-Wille and Rheinberger 2012: 184).

The previous chapter charted some lineages in terms of which science, beginning from its earliest form as natural philosophy, had formulated and attempted to answer the question of life. The very terms of both the question and the answers fashioned have changed manifold as the understandings and techniques of knowledge production developed with the passage of time. Thus we observed how conceptions of life in Western antiquity were largely informed by observing the visible world and speculating about the rest, while the late medieval period, which is often credited for the birth of modern science, emphasised on definitions of life that could be broken down into physical laws that were assumed to govern all of nature. Again, in the nineteenth century, the difference between life and inert matter became established as a disciplinary dogma, with biology becoming a separate science in itself; and, across into the twentieth century and beyond, when developments in different fields of knowledge, like those in genetics and cybernetics, came to inform how we conceptualise life and organisms. Indeed, the broad lines of this determination clearly amplify that what comes to be taken as a concept

in science is evidently being produced alongside its method (which further reinforces Canguilhem's formulation, writ large across the space of his corpus, rendering method as a whole way of knowing). The present chapter will try and extend these terms of engagement by critically revisiting moments in the history of biology/life sciences.

What we strive to do here is engage more fully with those developments in the history of biology/life sciences that pertain to establishing the knowledge of life by grasping its agents (that is, living beings). In the process, the chapter will seek to demonstrate some concepts and methods that have played a significant role in explaining biological life and its development, particularly those leading up to what Nikolas Rose has called the 'molecular gaze' in the contemporary era (see broadly Rose 2007). Rose, in his comprehensive narrative titled *The Politics of Life itself: Biomedicine, Power and Subjectivity in the Twenty-First Century* (2007), recognises that the 'molecularisation' of biology generally (and biomedicine, particularly) is neither a radically new situation nor something to be encouraged (or criticised) from an analytical point of view. Indeed, Rose is very clear that, in order to analyse the present, we do not need to begin with "familiar tropes of genealogy or 'histories of the present'" that seek to destabilize the present or mark its contingency (ibid.: 4). Rather, what he seeks to do in his wide-ranging narration is to draw a 'cartography of the present' that would take the present as its starting point and destabilize the future by laying bare the multiple possibilities that the present opens up to us. Consistent with this methodological strategy, Rose's detailed 'cartography' begins with the political-ethical conditions that make conceptualising and intervening in life possible in the twenty-first century. Having done so, it goes on to reconstruct some moments in the history of biology to draw a contrast from its present state. While this strategy enables a neat and well-laid out story of the 'molecularisation' of the life sciences, it invokes almost a teleological understanding of the history of biology, explaining developments of the past through their effects in the future.

Consequently, our aim and methodological strategy in the context of the present chapter is to resist attributing to science (even to the history of biology) such a telos. Such a strategy is underlined by the fact that if the present and the future can be understood in

the light of contingent conditions, then the past too should be reconstructed keeping in mind the contingent conditions of the time.¹ We focus specifically on histories of the gene, both past and present, but approach it in the way Evelyn Fox Keller (2000; 2002) does. For the latter, the gene is more of a model or a framework than a thing in itself, which allowed scientists to study living organisms more comprehensively. In fact, towards the end of her comprehensive survey of the century-long research on the gene - beginning with a rediscovery of Mendel's work in 1900 and ending with a plan of the first draft mapping of the human genome - Keller writes that the gene seems more to be a feature of the 20th century than of the 21st (see generally Keller 2000).

The current narrative thus begins with a prehistory of biology from its moment of differentiation from natural history. Indeed, in order to prevent any such teleological argument on the development of biology, we shall attempt to reconstruct the story (selective, nevertheless) through a critical epistemology of a trajectory in biology. In effect, therefore, what is being framed is *a* history of biology, and not *the* history of biology. Powering this narrative are moments in a disciplinary history when living beings were approached at different levels of their *organisation*, each yielding specific importance to the model of the gene.² The co-constitutive approach towards concept and method has been an important strategy in the philosophy and history of science (see generally Canguilhem 2008 [1966]), even as contemporary historians of science have rendered the overall approach as 'historical epistemology' (see Feest and Sturm 2011). We follow this strategy to analyse how the gene came to stand-in for life itself, becoming a 'powerful word' in 20th century biology and retaining its relevance in the contemporary era (see Keller 2000). We begin with the moment of the transition from natural history to biology, which following Foucault (2002 [1970]) one may render as the transformation from a taxonomic organisation of life to the living being itself. The living being, or the

¹ It is of course very likely that the sociologist Rose just did not feel the need to go through a more comprehensive history of molecularisation in biology and biomedicine, especially for a project that presents data assorted from a wide lens on the life sciences. However, for the purposes of our study, the turn to molecularisation needs to be contextualised in the larger history of biology that cannot just begin with the recourse to what is informally referred as the 'new biology' (see Kay 1993; Mukherjee 2016).

² As indicated in the previous chapter, life as organisation was an important tenet existing since the beginnings of modern biological thought, signalled particularly by Kant, even as biology developed separately from natural philosophy and natural history.

organism as composed of hereditary matter, comes to epitomise the concept of biological individuality in the 19th century, in the context of which biology as a nascent science undertook the dual task of establishing its object of study and differentiated itself from the physical sciences. The second moment is the transition from 19th century biology to molecular biology, when the emphasis comes to be on the mechanisms of the gene that make life possible. The third and final moment is one that follows from the consequences of molecular biology, and opens up the whole genome to intervention by human beings.

I. The Movement from Natural History to Biology

The case of biology is bound to intrigue scholars interested in analytical questions about the nature of science itself. Two facts make biology stand out from the other core natural sciences, namely, physics and chemistry. One, the formalisation of biology as a discipline followed from the preceding physico-chemical sciences, such that it became the most nascent natural science. Second, the fact that biology as a science is inseparable from its subject matter, which is living organisms, means that it has to constantly legitimise its existence as a science of the exact. This need of legitimisation stems from the fact that biological sciences themselves may not be able to elaborate on the exact distinction between life and inert matter (see Rosenberg and McShea 2008: 2). These specificities, in fact, constitute the domain of philosophy of biology, deliberating particularly on the question of “what is ‘life’ and whether things have a meaning or purpose beyond the merely physical and chemical processes that constitute them” (ibid.).

Interestingly, the aforementioned two facts about biology have often become points of contention in debates over its legitimacy as an autonomous natural science. Biologist Michael A. Simon, while discussing the nature of biology as a science, states that there has been a distinction operative in the sciences that differentiate the descriptive from the explanatory sciences (see Simon 1971). The descriptive sciences are believed to take the phenomenon as it exists in the world out there and describe its characteristics, or find generalities according to the observable properties of the phenomenon. The explanatory sciences, on the other hand, are those that aim to find the basis of such generalities and

explain them by formulating laws so as to grasp the behaviour of matter. However, philosophically this view is debatable, as all sciences seem to have shades of both description and explanation to some extent (Simon 1971: 8). With biology specifically, Simon points out that it can be considered descriptive as natural history, and it is explanatory insofar as biology can be reduced to biophysics and biochemistry. He goes on to describe natural history as offering “an index of regularities to be found in the world, plus an account of the sequence of states and events that have preceded the present state of things” (ibid.: 9). Alternatively, Gottfried Treviranus (who coined the word ‘biology’) has been credited with defining it as the study of “the different forms and phenomena of life, the conditions and laws under which they occur and the causes by means of which they are brought into being” (see Farber 1982: 145). Such summations present us with a useful entry point, but cannot be taken further from the perspective of the history of biology. In particular, we need to make sense of the movement from natural history to biology as one marked by a categorical shift in the object of study and the very nature of the scientific explanations invoked.

In what follows, we shall devote some attention to Michel Foucault’s (2002 [1970]) classic account of this transformation in the very epistemic basis of the scientific enterprise. Harking to an ‘archaeology of the human sciences’, Foucault diagnoses an epistemic shift from the Classical age to the Modern period in the way things came to be ordered, that is, the way in which they came to be organised in a grid or pattern of knowledge. Indeed, Foucault’s overall project in *The Order of Things* is to understand the conditions of possibility - as he terms it, ‘the historical *a priori*’ - that made things orderable and thus knowable in the history of Western culture. Specifically, Foucault’s archaeological inquiry into the birth of the human sciences brings out two discontinuities in the episteme of Western culture, one inaugurating itself from the middle of the 17th century (what he refers to as the ‘Classical age’) and the other articulating a turn from the 19th century onwards (classified as the ‘Modern age’). As he enunciates in the very preface of the book, the Classical age represented a specific modality of knowledge that was driven by the need to represent the thing as closely as it exists in nature, and accordingly identifies the domains of natural history, the analyses of wealth and value,

and general grammar to stand-in for order itself.³ This veritable space of order, as he explicates, exists between the

fundamental codes of a culture - those governing its language, its schemas of perception, its exchanges, its techniques, its values, the hierarchy of its practices - ... and the scientific theories or the philosophical interpretations which explain why order exists in general, what universal law it obeys, what principle can account for it, and why this particular order has been established and not some other (Foucault 2002 [1970]: xxii).

Classical Taxonomy as the Grid of Knowledge

Indubitably, the quest to know nature as such, the grid of knowledge available to the Classical age that made living beings known, was characterised by natural history, one devoted to charting out an ‘index of regularities’. Singularly, it is this aspect of finding regularities in nature that Foucault stresses in his account of natural history, which as it obtained in the period of the 17th century was a science of taxonomy devoted to classifying and naming living beings on the basis of their visibly observable properties (see Foucault 2002 [1970]: esp. Ch.5). He even credits the rise of natural history to the age of new curiosities, taking off from the larger edifice of the scientific revolution.

To be sure, natural history as it existed prior to biology was, in Foucault’s frame, far from being a philosophy of life. Rather, it was inextricably bound by a theory of language such that the only way in which a being could be made known was by giving it a name. The space opened up between words and things called for the naturalist to begin with a meticulous examination of the thing itself and transcribe the details in a well-framed language, rather than beginning one’s study on the basis of previous literature. What changed in the process was a new way of writing and doing history. Indeed, as Foucault adumbrates, for natural history to become a science, nature had to be defined as a realm in itself, and history had to be made natural (ibid.: 140). Roughly yet, before the mid-17th century, all that existed were histories of plants and animals, which (to echo Foucault) meant

³ For our purposes here, we shall limit our elucidation of Foucault’s argument to the historical transformation of natural history to the science of biology. In fact, this ‘historical *a priori*’ was what brought the theory of representation into a coherent relationship with the theories of language, natural orders and wealth and value.

[...] to write the history of a plant or an animal was as much a matter of describing its elements or organs as of describing the resemblances that could be found in it, the virtues that it was thought to possess, the legends and stories with which it had been involved, its place in heraldry, the medicaments that were concocted from its substance, the foods it provided, what the ancients recorded of it, and what travellers might have said of it. The history of a living being was that being itself, within the whole semantic network that connected it to the world (ibid.).

Put another way, Foucault here is suggesting that before the coming up of natural history as a discipline that found a way to *re-present* living organisms, a being was considered to be inseparable from everything that it had a relation with, including the environment. An entity (or even a concept like language or value) was approached as being part and parcel of the ‘semantic network’ which it constituted and of which it was constituted.

Clearly, a defining character of the Classical episteme was that signs that constituted a particular thing came to stand in as representations of that thing, rather than being that thing itself. The taxonomic table could isolate a being from its environment and arrange it in a table to find an order that constituted its relation with other beings. This reorientation, inevitably for Foucault, brought about the forging of a new relationship between words and things, inasmuch as words could function in place of things in the grid of knowledge, representing them in a certain order. The visible, and therefore visibility as a trained epistemological tool, mediated between the two. Indeed, as Foucault alludes, when the famous 18th century naturalist Carolus Linnaeus (1707-1778), popularly remembered as the ‘father of modern taxonomy’, professed that a living being had to be recognised on the basis of four definite characters – namely, structure, form, quantity and position - he was taking account of all that was part of the visible and yet beyond the surface level aspects of a plant or animal and which would enable highlighting its similarities and differences from other beings (Foucault 2002 [1970]: 146).

Without doubt, one can well see such a relationship existing in scientific atlases of the eighteenth century, which Daston and Galison have studied in order to conceptualize what they term “epistemologies of the eye” (see Daston and Galison 2007: Ch. 1). Indeed, in the place of Foucault’s ‘Classical episteme’, the two historians of science put

forth the idea of ‘epistemic virtues’.⁴ As they remind us, for the 18th century naturalists, the epistemic way of life was governed by the idea of ‘truth-to-nature’, categorised as chronologically prior to the virtue of ‘mechanical objectivity’ professed by the 19th century sciences. The historians’ quote directly from Linnaeus’s texts on botany, highlighting his methodology of capturing the attributes of a plant that are “constant, certain and organic” (Linnaeus, as quoted in Daston and Galison 2007: 59). The epistemic virtue of ‘truth-to-nature’, accordingly, imbibed a vision of finding regularities in the face of “untamed variability, even monstrosity of nature” (Daston and Galison 2007: 67). What governed the representative exercises of the 18th century naturalists was therefore a quest to show a being in its ideal (or typical) state, so much so that it did not contradict their ideals to beautify the image of the plant (or the human skeleton) in order to achieve perfection. Alternatively, as Daston and Galison remind, this possibility of showing more than what really is in order to beautify the ‘natural’ state of the plant, animal or human being - that is to say, “to improve nature by art” (ibid.: 74) - was entirely omitted from the methodology governing the 19th century sciences. Essentially, then, it is this epistemic way of life that made it possible for Linnaeus to exhort that variety is a florist’s knowledge, not the botanist’s, and that a genuine taxonomic exercise relied on differences between species, and not individuals (see Foucault 2017 [1969]: 211).

It should be stressed that, in its exercise of building a taxonomy of living beings, natural history began with the assumption that nature is continuous. What this meant is that the classification of all living beings as devised by Linnaeus in the 1700s was supposed to be purely descriptive, rather than prescriptive (see Mukherjee 2016: 20). Such a description of the natural world was supposed to serve the purpose of finding similarities and differences across the realm of living nature. Of course, it was Aristotle who proposed the earliest taxonomic system in the history of Western knowledge, stressing that species were real entities that exist in nature (see Claridge 2010). This was the

⁴ By way of a definition, they state: “Epistemic virtues are virtues properly so called: they are norms that are internalised and enforced by appeal to ethical values, as well as to pragmatic efficacy in securing knowledge ... Epistemic virtues earn their right to be called virtues by moulding the self, and the ways they do so parallel and overlap with the ways epistemology is translated into science” (Daston and Galison 2007: 40-41).

tradition that natural history inherited whereby scientific knowledge began from the level of species. Taxonomy, in other words, was a science of species (see Foucault 2017 [1969]: 211). But the differences in the methodologies of classical taxonomists ensured that not everyone agreed with the ‘reality’ of species correspondingly. Some like Charles Bonnet (1720-1793) and Comte de Buffon (1707-1788), equally important figures in 18th century natural history as Linnaeus, invoked the continuity of nature to formulate a belief in the fixity of taxons like species, variety, genera etc. Even more emphatically, in his prescriptive speech on the style of discourse that should be adopted by naturalists, Buffon points out:

Our general ideas are relative to a continuous scale of objects of which we can clearly perceive only the middle rungs and whose extremities increasingly flee from and escape our considerations ... The more we increase the number of divisions in the productions of nature, the closer we shall approach to the true, since nothing really exists in nature except individuals, and since genera, orders, and classes exist only in our imagination (Buffon, as quoted in Foucault 2002 [1970]: 160).

What Buffon offers with this quotation is not only a theoretical argument on the continuity of nature - which regards that only individuals exist in the last instance - but also the practical problem of fixing the boundaries of each taxon. Where do species end, for example, and genera begin? Buffon’s answer would be that such “general ideas” will always be relative in the face of how nature presents itself. Indeed, this problem became more pronounced for naturalists working in the latter part of the 19th century when the huge quantity of specimen, collected from across the world in the second phase of colonisation, were brought back to museums of natural history in London, Paris, Berlin and other European cities that became centers of artefactual collection and research (see Farber 1982: 148).

All the same, regardless of such differences, one can assume (following Foucault) that the naturalists were working with the same episteme, involved in finding order through repeated tabulation of living beings, based on their morphological character. Of course, in finding regularities in nature, natural historians necessarily worked with the notion of continuity of nature (see Foucault 2002 [1970]: 160), an idea conceptually serving as a kind of evolutionism before Darwin’s epoch-making theory, albeit one with an entirely different epistemic basis and consequence from modern evolutionary thought (ibid.:

164). To be sure, in Darwin's formulation, as briefly indicated in our previous chapter, life forms were a result of the interaction between the individual being and its environment. Indeed, as Farber has also noted, the Darwinian theory of evolution was what led to the shift from a structural to a historical conception of order in nature, and thus to a historical understanding of the generation of life forms (see Farber 1982: 150).

Within 18th century natural history, by contrast, evolutionism translated the problem of generation of life forms either as a spontaneous generation of already given forms in nature or as the movement from the most rudimentary to the most perfected form (see Foucault 2002 [1970]: 295). In other words, continuity on the one hand could imply that nature had, since the very beginning, all the possible matter from which the present species have developed by permutations and combinations. On the other hand, continuity was also being interpreted as allowing for a logical progression from an archaic prototype (symbolised by the fossil) towards the most complex form (that of the human being) [ibid.]. In such an understanding, continuity exists because an inherent order exists, not because of the historical interaction between a living being and its environment. The key question, accordingly is the following: what then changed from this way of perceiving living beings and their formation to the 19th century theories of evolution, most prominently that of Darwin?

From Species to the Organism Itself

Clearly what changed was the need to go beyond morphological differences so as to build a table for representing living beings, but to look at the thing-in-itself, that is to say, to look at the organism itself, and not the species to which it belonged. If in the movement from natural history to biology, what changed was that life itself became an object of analysis, as Foucault is urging, then surely it was because the organism itself emerged as a problem to be thought of and conceptualized. Clearly, various patterns of thought and processes were at play with the shift of gaze towards the organism. One was the fundamental separation between life and non-life, the organic and the inorganic: the organism was that which had life and the inorganic was that which lacked life. This consciousness was clearly lacking in the Classical episteme of the naturalists. Linnaeus,

for example, included a taxonomic table classifying minerals in his classic text '*Systema Naturae*' that established the binomial system of naming species.⁵

Certainly, grasping what happened to research in physiology during the period of the 18th and 19th centuries would help us in understanding how an individual came to be perceived in biological terms. Equally informative would be a discussion across branches of biology oriented to showing how the turn from the vocabulary of species to that of the 'organism' and the 'milieu' was a product of the epistemological conditions in which science was done. The concept of 'milieu' came to be used as a frame of reference calling attention to both the external environment of a being as well as its internal constitution. Indeed, we had in the previous chapter traversed a set of developments through which the 19th century physician Claude Bernard (1813-1878) came to refer to the 'inner milieu' of an organism. As we briefly contemplated thereon, the conceptual antecedent of this idea was laid down a quarter and a half century earlier by the Kantian idea of 'autonomy' as self-legislating, which was further transposed to the notion of an organism as founded on a capacity for self-organisation (see Keller 2005). What links the study of morphology by naturalists of the eighteenth century to the concept of organism and its 'inner milieu' is precisely the work carried out by anatomists and physiologists in the meanwhile. In other words, what was being added to the knowledge of form is the further idea of the structure and function of the organism. Precisely, to know what constituted the form of organisms was to strip open the inner space that remains otherwise invisible from its external form and structure.

The key to this alternation between natural history and biology, as Foucault (2017 [1969]) reminds us, is the French naturalist and zoologist, Georges Cuvier (1769-1832), who working in the cusp between the 18th and 19th centuries 'redistributed' existing biological knowledge of the living being as a historically developed entity. Of course, within anatomical knowledge as it developed till the 18th century, organs as the visible constituent of a body were recognised by both their function and structure, which were

⁵ 'How biology pioneer Carl Linnaeus once tried to classify minerals'. Retrieved from <https://www.forbes.com/sites/davidbressan/2016/06/16/how-biology-pioneer-carl-linnaeus-once-tried-to-classify-minerals/#2706eb4e6afction>.

classified independent of each other. But, importantly enough, through his development of comparative anatomy, Cuvier gave preference to function over structure of an organ, given that the organs for the same function may be visibly quite different across species. Evidently, such a framework still rested on species as the unit of analysis, and used the method of first recognising the common functions of life that exist in all species (respiration, digestion etc.) and then comparing the specific organs or parts at work across different species. Importantly, even as Cuvier approached the specific organism to study its anatomical constitution, the categories he formulated for classification were analysed at the level of species. For this reason, precisely, Foucault characterises Cuvier's situation in the history of biology as an intermediary one between taxonomy and life (see Foucault 2017 [1969]).

Another distinctive contribution of Cuvier was in establishing palaeontology as the study of an organ's interaction with its milieu, as manifested in different species. Even as he thus stayed true to the species concept, Cuvier was able to recognise that totalities can exist within an individual as well as in species. In fact, what he called "the necessary conditions of existence" for living beings was a confrontation or interaction between two totalities, the anatomo-physiological constitution of an organism and its taxonomic position (see broadly Foucault 2017 [1969]). One could perhaps deduce from these arguments that Cuvier had cleared the ground for Darwin's evolutionary theory that found a concrete way to bind ontogeny with phylogeny - the development of an organism and its evolutionary relation with other life forms - in the individual itself. Furthermore, it must be noted that in his methodology Cuvier lay close to 19th century physiology, which was for most part dominated by Claude Bernard and his strict adherence to experiment as the paradigmatic method in biological science (see Daston 2005: 16).

Obviously, with his demonstrative work in anatomy, Cuvier combined the knowledge of structure of the organ with its function, even as a strict difference still obtained between the two. The study of function was traditionally the domain of physiology, explaining the kinetic (or functional) part of the organism as opposed to the static (or structural) aspects discovered by anatomy (see Woodruff 1921). Cuvier's contribution, as Foucault

urges, consisted in the transformation from a taxonomic to a ‘synthetic notion of life’, referring to the synthesis of structure and function, the visible and the invisible (Foucault 2002 [1970]: 293). This synthetic notion of life, evidently, followed new principles. Indeed, the logic behind Cuvier’s closer attention to function over morphology and structure as part of his synthetic conception was manifested in the law-like principles he formulated in anatomy, taking inspiration from Newtonian physics. In thus foregrounding a functional unity of the organism, Cuvier established that there is a coexistence of parts or organs, and an internally hierarchical organisation that creates a relation of interdependence in organic structure. The interaction of the visible differences of structure and the invisible similarity of function made, in other words, the constitutive milieu of the organism (see Foucault 2002 [1970]: 294). In other words, organisms had an underlying similarity because of how they came to be constituted, not because they all could be arranged in a table. In a parallel formulation, we can say that the law of internal hierarchy also lays the ground for the hierarchical science of biology (see Mayr 1997, for an overview).

Significantly, what Foucault explores with Cuvier’s contribution, Dennett (1995) does with Charles Darwin (1809-1882). If Cuvier did the background work for approaching the organism as a whole by duly acknowledging its internal constitution, Darwin gave a vocabulary proper to believe in and consolidate the organism. If Cuvier wanted to unravel the organism by accounting for specific differences, Darwin wanted to explain the problem of ‘speciation’ (that is, the generation of diverse species) by understanding how individual differences occurred. Dennett thus sharply reminds us that Darwin’s theory is not only about the evolution of species that disturbed their immutability - thereby shaking the very epistemic ground of natural history - but also builds a case for evolution by natural selection (see Dennett 1995: 39). Existing species could only have evolved from those in the past - a principle that Darwin called ‘descent by modification’ – and, in acknowledging so, was appreciating the ‘design’ within organisms, rather than their diversity (ibid.: 42-44). This ‘design’ was precisely the ability of the organism to respond to its environment, modify itself in the process of development, and pass on the

modifications attained to its offspring.⁶ As with the Kantian idea of self-organisation, Darwin had also liberated the organism from an external designer.

Over to Heredity and Genetics

To be sure, with reference to the two principles of descent by modification and natural selection, Darwin had a strong explanation for the latter through recourse to the Malthusian theory of population growth (Dennett 1995: 40). But to fully explain his principle of descent by modification, Darwin seemed to lack an exact mechanism. Evidently, the concept of heredity had existed in Western knowledge since the ancient Greeks, principally by posing the question of how like begets like from one generation to another (see Mukherjee 2016: 20).⁷ However, none of the explanations could be harmonised with Darwin's theory of evolution. The latter's principle of descent by modification sought to explain life and living organisms through qualities of both stability and variation (or, in the language of classical taxonomy, both similarity and difference). Interestingly, in his desperate attempts to devise a theory of heredity without any experimentation, Darwin had formulated an idea that all the cells of an organism contained particles carrying information, what he called 'gemmules', which emanating from both the parents came to be blended in the moment of fertilisation of the offspring (see Mukherjee 2016: 42-43). Even as Darwin had foreseen the constituent matter of genes, the mechanism of blending that he suggested was almost a replication of past theories of inheritance, including those of Pythagoras and Aristotle (ibid.: 43).

As Brian and Deborah Charlesworth (2009) note in their lucid review article on the conceptual relationship between Darwin and genetics, the blending mechanism of 'gemmules' through which acquired traits were passed on to the next generation was a

⁶ Palpably, Dennett's invocation of 'design' within the Darwinian conception of organism is also gesturing towards ideas about the genetic program that would become popular in the 1960s. Indeed, Dennett exclaims much later in the work: "Darwin's great insight was that all the designs in the biosphere could be the products of a process that was as patient as it was mindless" (Dennett 1995: 188).

⁷ Emblematic of this would be the aspects of Pythagorean theory, which states that all the hereditary information existed in the semen (and which, in eighteenth century embryology, was famously rehashed as 'preformation'), as also Aristotle's theory of 'epigenesis' that separated the form of the organism from its matter, the former coming from the father and the latter provided by the mother (see Mukherjee 2016: 21-24).

hypothesis that Darwin took to be an experimentally established fact, even though he himself was not confident enough about it. A significant limitation to the blending mechanism, as was noted in a review of *On the Origin of Species* in 1867, was that if particles blended into each other, then all traits would be diluted in a matter of a few generations to create new ones. In other words, nothing would ensure the permanence or stability of a trait in a species over time (see Charlesworth and Charlesworth 2009; also Mukherjee 2016: 44). In short, the hypothetical mechanism of inheritance that Darwin suggested was incompatible with his own theory of evolution that ensured both stability and variation of character.

It is precisely within this conceptual lacuna that Gregor Mendel (1822-1884) placed himself and his experimental method of cross-pollinating pea plants. These experiments, all conducted between 1856-1863, culminated in establishing a way of constituting the organism through what came to be known as Mendelian principles of heredity. Arguably, the most crucial fact that Mendel - posthumously recognised as the father of genetics - had realised through his experiments was that individual traits did not blend with each other, but were rather expressed through some kind of natural selection within the offspring. The traits that were selected in one generation were termed as ‘dominant’ by Mendel, and those that were not expressed were termed ‘recessive’. However, the same recessive traits of one generation of the hybrid organism reappeared in the cross-pollination of one hybrid with another, thus becoming dominant in their offspring. The breakthrough that Mendel had achieved was to conceptualise that “a ‘hybrid’ organism [-] was actually a *composite* - with a visible, dominant allele and a latent, recessive allele (Mendel’s word to describe these variants was *forms*; the word *allele* would be coined by geneticists in the 1900s)” [Mukherjee 2016: 51, emphasis in original].

Thus, if Darwin had used the organism for speculating about the problem of speciation, Mendel had, by staying true to the experimental spirit of the 19th century, used the organism as the experimental model to know its exact composition. Darwin’s question, as Mukherjee puts in perspective, was ‘macroscopic’ in nature, that is to say, how organisms transmute information about their traits over a thousand generations? On the

other hand, Mendel's question (one that further governed his method) was 'microscopic' in nature, answering how a single organism is able to transmit information over a single generation to its offspring (see Mukherjee 2016: 31). The roots of the idea that organisms are composed of information thus go back directly to Mendel and his experiments with pea plants. Following Cuvier's 'anatomic disarticulation' of the organism (Foucault 2002 [1970]: 294), Mendel had proposed a strong hypothesis about the fundamental units of heredity that assembled the organism. Indubitably, units of heredity in an organism not only provided the invisible and deeper level of identity common across all life forms; they also held the key to difference and variation on the surface.

II. The Movement towards Molecular Biology

As biology established the organism as its object of study towards the end of the 19th century, the question sought to be answered next was what made the organism possible; in other words, what were the building blocks of the organism? One way in which both Darwin and Mendel had sought to answer the question of fundamental constituents of the organism was to evaluate how the character traits of the parents were passed onto the offspring. This, as was implied above, was the study of transmission of traits which came to be unified under the science of heredity. Thus the initial period of the study of genetics was dedicated to studying the specific characteristic of genes that Darwin could not recognise, and that which Mendel had gotten hold, that is, the study of stability of traits from one generation to another (see Keller 2000: 14). However, the stability of traits, as biologists would find out by the middle of the 20th century, was inevitably tied with the very dynamics of variation. Clearly, biological thought about how genes constituted organisms would be moving back and forth between structural and functional analysis (ibid.: 12-14).

Other accounts of the gene (Griffiths and Stotz 2007; as also Mukherjee 2016) seem to follow this historical but nonlinear movement in disciplinary knowledge between thinking about the structure and the function of the gene. In fact, Griffiths and Stotz

approach the entire discourse of the gene within biology through this logic when they write:

In our view, one of the clearest themes in the century-long evolution of the concept of the gene is the dialectic between these two conceptions of the gene, a structural conception anchored first in cytology and later in biochemistry, and a functional conception anchored in the observable results of hybridizations, at first between organisms and later directly between DNA molecules (Griffiths and Stotz 2007: 86).

Within this logic, if classical genetics modelled itself on studying heredity by linking genes with a particular character trait, then molecular biology generally, and molecular genetics particularly, was configured by the discovery that the carrier of genetic information was the DNA molecule, located in the nucleus of the cell. Not surprisingly, following this threshold, classical genetics is often differentiated from molecular genetics, with the latter changing both the methods and techniques of approaching genetic material as well as its conceptions of human knowledge (see broadly Keller 2000; as also Barnes and Dupre 2008). We will adopt this bifurcation to present the history of how the gene came to be known in both its structure and function. In any case, the very term ‘movement’ (as indeed ‘moment’) suggests a binding together of what preceded with what followed even after the recognition of a threshold, and in the process underscores both continuity and discontinuity.

More on Classical Genetics and the Problem of Heredity

Classical genetics is an oft-repeated story, often subsumed under a broad canvas incorporating a host of scientists whose questions were not necessarily the same. Yet it cannot be denied that the field of genetics had taken upon itself the imperative to solve questions of heredity which had a genealogy of its own outside of scientific thought, such as in the philosophies of preformation and epigenesis.⁸ In their comprehensive text on the history of genomes, Barnes and Dupre note that “classical genetics should be understood as the product of its own ancestry” (Barnes and Dupre 2008: 20), while going on to underscore the two major systems of knowledge that classical genetics had

⁸ As already implied in the foregoing pages, but see further Muller-Wille and Rheinberger (2012: Chs.1-3) for a comprehensive history of ideas surrounding heredity beginning from the 16th century that influenced the work of classical geneticists. Going into that history may not be directly useful for our purposes in this chapter.

inherited. One was the taxonomic knowledge of species undertaken by naturalists who classified species according to the visible character traits of adult organisms, which later came to be known as ‘phenotype’. The second ingredient in the cultural inheritance of genetics was the necessary preceding development of cell theory, popularly credited to the work of the 1830s and thereafter. Cell theory, as Barnes and Dupre remind us, had established ‘ontogeny’ as a fact of life, taking for granted that all organisms developed from a single cell, which then multiplied, differentiated and ultimately died in the process of organismic development (ibid.).

It was in this discursive context that Mendel’s thinking of the “particulate entities” (Keller 2000: 19) that travelled from one generation to another began to take shape. Not surprisingly, Muller-Wille and Rheinberger (2012) dispel some notions prevalent in popular histories of the gene that project Mendel’s alienation from the larger community of biologists as a cause for the consequent ignorance of his work for almost half a century. They insist that, through his education at the University of Vienna, Mendel was well versed with the prevalent cell biology and evolutionary theory of the time. They even succinctly argue that if Mendel was a ‘misfit’ in his time, it was because of the idiosyncratic nature of his work - the specific techniques he used - even though (as they insist) it was consistent with the hybridisation experiments popular in the nineteenth century that had found their application in the agro-industrial context of the time (see Muller-Wille and Rheinberger 2012: 133 ff). Indeed, it is for this specifically experimental context of studying genes that classical genetics is often referred to as Mendelian genetics, even as the latter’s laws of inheritance were to later prove insufficient.

The insufficiency of Mendelian genetics was made apparent for the first time in the mutation experiments of Thomas Hunt Morgan (1856-1945), whose work we shall discuss in course. All the same, in the dominant literature coming from the beginning years of the 20th century, an almost reductionist form of ‘Mendelism’ persisted in an attempt to formulate laws that Mendel himself had not suggested with much confidence

(see Barnes and Dupre 2008: 19).⁹ Indeed, the roots to this reductionism lay in the fact that the gene was to serve only an instrumental purpose in the beginning years of classical genetics as its material form was not yet known (see Griffiths and Stotz 2008). Clearly, genes were, in this period, ‘hypothetical entities’ (Keller 2000: 19), and the two major players of this juncture hypothesising about the gene were the zoologist August Weismann and the botanist Hugo de Vries. Weismann’s (1834-1914) point of interest was “How is it that ... a single cell can reproduce the tout ensemble of the parent with all the faithfulness of a portrait?” (Weismann, as quoted in Keller 2000: 16). Weismann had, largely independent of Mendel’s work, speculated the presence of “particulate, self-reproducing ‘elements’ that determine the properties of the organism” which he called ‘determinants’ (see Keller, *ibid.*). Additionally, he was able to foresee the presence of the totality of these determinants in a substance “of a definite chemical, above all, molecular composition” which he called the ‘germplasm’ (*ibid.*: 17). Interestingly, Weismann’s experiment involved surgically excising the tails of rats for five generations to determine if their offspring mice would be born tailless, which they certainly did not (see Mukherjee 2016: 57). He had thus provided experimental proof against Darwin’s ‘gemmule’ theory, much like Mendel, by suggesting that hereditary material does not blend at all but remains intact (Mukherjee, *ibid.*).

A similar challenge to the blending mechanism was posed by de Vries (1848-1935) in 1897, when he postulated through his cross-breeding experiments with various kinds of plants that no information was lost in the transmission of particles from one generation to the next through the sperm and the egg (see Mukherjee 2016: 58). These particles were termed by de Vries as ‘pangenes’ bringing together Darwin’s ‘pangenesis’ and Weismann’s ‘determinants’ (see Keller 2000: 16). If for Weismann, the stability of traits across generations was ensured by the entire molecular composition taken as a whole, for

⁹ The application of these ‘laws’ assuming fixity and compliance was taken to its extreme end by Darwin’s cousin, Francis Galton, when he defined heredity as the science of improving stock. However, even if we keep the question of eugenics aside in the phrase ‘improving stock’, the notion of strict lawfulness or “(h)ard heredity, the notion that the hereditary material is fixed once and for all at conception and unaffected by changes in the environment or phenotype of the parents ... *can be seen as the key conceptual move that created the epistemic space within which the Mendelian notion of a particulate and stable hereditary material (later christened the gene) could be situated*” (Melloni 2016: 1, emphasis added).

de Vries, it was ensured by the individual particles, each representing a trait, and speculated to inhere in the nucleus of the cell. All the same, both Weismann and de Vries agreed to the fact that units of heredity functioned as the fundamental units of biology, as atoms and molecules were for physics and chemistry respectively (see Keller 2000: 16).

In 1900, the year famously remembered for the rediscovery of Mendel's paper on hybridisation of pea plants, de Vries was forced to look beyond his initial results and ask the question of how variants arose in the first place (see Mukherjee 2016: 60). Solely through experimental results, de Vries was able to conclude that new variants of a particular plant arose spontaneously, that is, by random chance (ibid.: 61). Moreover, as was claimed, these spontaneously generated variants were hereditary and subjected to natural selection in the fight for survival. In this conclusion, lay the seeds of what would come to be controversially known as the 'Modern Synthesis', bridging the gap between Darwin and Mendel - evolution and genetics- and establishing the fact that selection operated not on the organism as a whole but on its most essential parts, the units of heredity (ibid.:110-11). De Vries called these variants 'mutants', constantly changing features of evolution, putting in motion what Keller consolidates in the phrase "motors of stasis and change" (Keller 2000: 11).

On the Threshold of Gene

It must be noted that the terms such as 'determinants', 'pangenes' or 'mutants' were still by the turn of the 20th century used in an instrumental fashion, and lacked any material basis. Around the same time, the dogmatic distinction between the organic and inorganic within biology was fading away, giving way to experimental studies on 'model organisms' identified as representing the "most general properties of living beings" (see Muller-Wille and Rheinberger 2012: 127-28). However, by the first decade of the century, the growing number of studies generalising the idiosyncratic properties of these model organisms as 'properties of life' needed to be categorised in some way within the discipline. In fact, to fill this lacuna, William Bateson (1861-1926), another prominent Mendelian, proposed to call this new discipline by the name of 'genetics', following

which the botanist Wilhelm Johannsen (1857-1927) coined the term ‘gene’ that was to become the object of this new study (ibid.: 128). In fact, according to Johannsen’s now famous statement:

The word ‘gene’ is completely free from any hypotheses; it expresses only the evident fact that, in any case, many characteristics of the organism are specified in the gametes by means of special conditions, foundations, and determiners which are present in unique, separate, and thereby independent ways- in short, precisely what we wish to call gene (Johannsen, quoted in Keller 2000: 2).

Significantly, in freeing the gene from any hypothesis, Johannsen had still retained the bare minimum quality of transmission of traits that no one in the scientific world could dispute by then.¹⁰ Keller (2002) therefore diagnoses a necessary ambiguity that prevailed in the term ‘gene’, one carried forward from the ambiguity of ideas inherent to heredity itself. Succinctly, formulations of the Mendelian character after Mendel in terms of ‘determinants’ or ‘pangenes’ was testimony to the fact that at the end of the nineteenth century a science of the hereditary phenomenon “encompassed both the study of conservation of traits across generations and their intragenerational emergence (or transformation) over the course of an organism’s development from a fertilised egg” (Keller 2002: 123-24). The word ‘gene’ thus inherited its dual connotation, referring to both the particulate entities (the ‘atoms’ of biology) as well as to the organism (ibid.: 126).¹¹

The order of these complications became operational in the disciplinary separation of genetics and embryology at the beginning of the twentieth century, with the former addressing the phenomenon of transmission and the latter development. Though defined as separate agendas at this disciplinary level, this distinction had its conceptual limits for understanding the intermingled processes of transmission of traits and their formation in the life of the organism. By the 1930s, therefore, geneticists and embryologists had

¹⁰ This was evident in his formulation of the terms ‘genotype’ and ‘phenotype’ that distinguished the hereditary material that is transmitted in the process of generation from the character traits that are visible on the surface of the organism. The distinction was also an effort to “distinguish between the Mendelian character itself and the Mendelian factor ‘underlying’ it” (Griffiths and Stotz 2008:86).

¹¹ As Keller had noted in her earlier formulation, in the period of classical genetics, the gene often stood for both elementary particles and life itself. She notes explicitly that “it was just such an implication that had led Hugo de Vries to argue that these units were ‘not the chemical molecules; they are much larger than these and are more correctly to be compared with the smallest known organisms’” (Keller 2000: 47).

begun realising the limits of this distinction for their work. It is to be noted that there was still no clear cut knowledge of what a gene is or how it functions. Indeed, to think of transmission and development together, biologists needed a shared vocabulary to continue their work (see Keller 2002: 124). What subsequently grew to fill this ‘lexical gap’, as Keller calls it, was a discourse of ‘gene action’ that enabled biologists to separate the knowable from the unknowable at a particular moment in the discipline (ibid.: 129).

The idea of ‘gene action’ was principally employed as a term to refer to the capacity of genes to act in the making of character traits (see broadly Keller 2000 and 2002). It provided the basis of a common lexicon to refer to genes and their properties without knowing the exact mechanism of their function. Thomas Hunt Morgan’s work was an important precursor to this meaning of the gene. Beginning in 1905, Morgan had performed extensive breeding experiments on the fruit fly in an attempt to answer the question of where genes can be located in the cell (see Mukherjee 2016: 93-94). Drawing on the work of embryologists who had proposed the chromosomal theory of the gene, Morgan’s experimental data had shown that genes were located inside chromosomes in the nucleus of the cell (ibid.). Additionally, he had made an important modification to the Mendelian theory of inheritance, by positing that genes bunched together and travelled in packs rather than being an independent or discrete entity (ibid.: 95). As was explained, the reason why some traits almost always coexisted was because the genes for those traits were physically linked to each other in the chromosome.¹² Morgan had thus transformed the gene from being a purely hypothetical entity to being a “material *thing* that lived in a particular location, and a particular form, within a cell” (ibid., emphasis in original).

As should be discernible, Morgan believed that a theory of the gene was necessary to account for its causal agency, even if geneticists had not yet found out the exact

¹² In certain cases, yet, Morgan had found out that a gene could unlink itself from its pack, swapping places from the maternal to paternal chromosome (and vice versa), a phenomenon that was referred by him as genes ‘crossing over’ (see Mukherjee 2016: 96). Mukherjee mentions specifically that this discovery would in the future “launch a revolution in biology, establishing the principle that genetic information could be mixed, matched, and swapped - not just between sister chromosomes, but between organisms and across species” (ibid). The future allusion here is clearly to the recombinant DNA technology.

mechanism of its function (Keller 2000: 46). However, this acknowledgment of a causal agency was also the source of attributing some curious properties to genes. As Keller succinctly puts it in perspective: “At one and the same time, the gene was bestowed with the properties of materiality, agency, life, and mind” (ibid: 47). One may observe here a certain characterisation of the gene in terms of vitality, given that the term ‘gene action’ implied agency to act. This vitality, though, was conferred purely in the realm of speculation in the period of classical genetics. More importantly, as a discourse that persisted from the 1920s to the 1960s, ‘gene action’ served as a metaphor and a tool to index the uncertainty that inhered in the gene as a thing, keeping under wraps both its exact structure and function (see Keller 2002: 130).

Pathways to the Molecular Gene and a New Science of Life

The causal authority of genes, as a fundamental assumption of classical genetics, had left open the question of what they are and how they function. Both the structure and function of the gene were soon to become clearer with the integration of an ensemble of physical and chemical procedures prevalent in the understanding of living systems (see Muller-Wille and Rheinberger 2012: 162). In fact, these two thoughtful historians’ argue that the molecularisation of genetics was not a direct consequence of the experimental regime of classical genetics; it was rather part of an all-encompassing movement towards molecularisation of biology which was simultaneous to, but independent of, classical genetics. This broad movement was driven with the aim “to understand the conformation and function of biologically relevant molecules beyond their mere atomic composition” (ibid.). Indeed, it was this task that attracted a number of physicists and chemists into biological research in the early decades of the 20th century.

But the more pertinent question is: why and how did molecules become relevant to biological research in the first place? Molecular biologist and historian of science, Michel Morange (2008) hinges this curiosity on the progressive movement towards lower levels of organisation in explanations of biological life. As he points out, the downward movement in the history of biological descriptions, beginning from organisms, organs and tissues in the 18th century, cells in the 19th century, to subcellular structures like

chromosomes in the 20th century, were all aided by improvements in optical devices over time (Morange 2008: 32-33). In fact, the 20th century witnessed the revolutionary introduction of the electron microscope that was able to penetrate the subatomic levels of matter and address “a domain of the living world that had previously been partially absent from the description” (ibid.: 33). This technological effort was in turn associated with the need to “naturalise” life so as to uncover the mysteries of the deep functioning of organisms. Morange thus forcefully points out:

The sheer ignorance of what constituted the ‘living’ was considered as an intellectual scandal by many scientists, in particular physicists. This scandal became more obvious with the rapid progress made in physics in the first three decades of the twentieth century: matter and energy had been fully naturalized. The same had to occur with life (ibid.).

In fact, Lily E. Kay (1993) invokes a similar motivation for the molecular ‘vision’ of life when she points out that the tools of research in biology had changed from simple petri dishes and light microscope to electron microscope, x-ray diffraction and spectroscopy among others. Most of these techniques were exclusive to experimental physics, until physicists themselves began to get interested in problems of biology, making their techniques a part of what Kay calls the ‘technological landscape’ of new biology laboratories (Kay 1993: 5). A new field of biology thus came to approach life at a sub-microscopic level. What followed was an interdisciplinary field of life sciences that integrated methods from physics, chemistry and mathematics, as well as from embryology, genetics, microbiology, physiology and immunology (ibid.).

Undoubtedly, we get a particular characterisation of the molecularisation of genetics from the above descriptions. In fact, rendered as a historical field of science, the molecular gene came to be situated as part of the ‘molecularisation’ of biology. As a concept, clearly, the molecular gene came into existence as part of ‘naturalising’ life and steering clear of any metaphysical mysteries around it. Methodologically too, as we saw above, molecular genetics took shape as part of the enabling technological landscape of the time. All in all, it is this gathering of ‘history, concept and method’ (as in Canguilhem’s frame) that becomes central to grasping the movement of science and scientific objects such as the gene. More foundationally, these historical, conceptual and methodological repertoires of the molecular gene throw into sharper relief the question

of what really constituted this new science of life (incidentally, often referred as ‘new biology’). Here again, Thomas Hunt Morgan was a key player in the elucidation of the term when he contrasted the ‘new biology’ from the old. New biology, as Morgan described it in 1928, developed its object of study by emphasising on the unity of life, as opposed to its diversity (see Kay 1993: 4). With such an aim, it would be only prudent to study vital phenomena at their bare minimum level and address aspects of causation in an upward movement (that is to say, from the smallest and most fundamental parts to the aggregated state of the body) [ibid.]. Thus what followed the experiments on the house fly, as popularised by Morgan, was its replacement by bacteria and viruses as model organisms of the new biology.

Equally noteworthy is the fact that both Morange (2008) and Kay (1993) follow the same periodisation for the birth of molecular biology - from the 1930s onwards - thus challenging historical accounts that equate the molecular vision with the informational metaphors of life, following from the Second World War.¹³ Morange emphatically brings together the view of genes with the birth of molecular biology when he writes:

Molecular biology is not merely the description of biology in terms of molecules. ... Rather, molecular biology consists of all those techniques and discoveries that make it possible to carry out molecular analyses of the most fundamental biological processes - those involved in the stability, survival, and reproduction of organisms. ... Molecular biology was born when geneticists, no longer satisfied with a quasi-abstract view of the role of genes, focused on the problem of the nature of genes and their mechanism of action (Morange 1998, as quoted in Falk 2009: 175).

All the same, in order to situate the implications of molecular biology in understandings of the gene, one needs to recount the history of events through which the gene came to be recognised as a molecule. Indeed, taking off from the preceding sub-section, the immediate context in which the words ‘gene’ and ‘action’ were conjoined came specifically from chemistry, whereby chemical enzymes were recognised to be acting in, or enabling, a reaction between two or more substances (see Keller 2002: 130). Early

¹³ The informational paradigm, as was discussed in the concluding pages of the previous chapter, served as an important metaphor of life especially in the post-war period. It is possible that the disagreement between historians on the temporal convergence of the molecular vision and information theory, in turn emerging from the development of computer science and communication after the Second World War, is the gap between the larger discourse of life and the disciplinary emergence of molecular biology in discussing genes.

biologists like Weismann had long back hypothesised the molecular structure of the gene, as we have already noted. But the limitation that classical genetics faced in capturing the gene in its chemical form was based on the assumption that genes only travelled vertically from parent to offspring, making them a part of the already formed cell and thus inaccessible to direct observation (see Mukherjee 2016: 111). They were thus limited to studying the transmission of traits by means of creating natural mutants through cross-breeding organisms, which obviously was a time consuming process (ibid.).

In fact, beginning in the 1920s, scientists from different fields had begun to probe into the chemical constitution of the gene, by altering the organism through new available techniques. While the details of these experiments need not concern us - Mukherjee (2016: 112-14) enacts these scenarios – the breakthroughs recorded came to consolidate the idea that the gene “whatever it was, was capable of motion, transmission and of energy-induced change - properties generally associated with chemical matter” (ibid.: 115). By this time, besides, biologists had gained new knowledge that the whole genome, the totality of genetic material in an organism, was highly malleable, even that there was no fixed rate of mutations in a species and that genes were information carrying chemicals that showed some quality of autonomy (ibid.).¹⁴ Clearly, the probe into the gene as a biochemical entity had opened up questions of its function and the mechanisms through which it carries those functions (see Keller 2000: 20; also Griffiths and Stotz 2008: 88).

By the 1940s, the burgeoning group of biochemists interested in genetics had broken down cells to recognise the various molecules in living systems, but the search for the gene carrying molecule was still on (see Mukherjee 2016: 133-34). It was, however, known by then that genes resided in the biological structure of chromatin, which in turn was composed of two chemicals, namely, proteins and nucleic acids (ibid.: 134). Further work on this front finally resulted in the finding that it is DNA, one of the two molecules other than RNA composing nucleic acids, that carried genetic information (ibid.: 137).

¹⁴ Note the term ‘genome’ was introduced in the vocabulary of biology by Hans Winkler in 1920 to refer to the totality of genetic makeup of an organism (see Weissenbach 2016). However, the term does not come into widespread use before the popularity of molecular biology in 1950s and 60s, considering that the structure and function of individual genes is the focus of biology till the latter period.

Evidently, the experimental uncovering of molecules inside the cell was not directly motivated by broader questions of either genetic stability or developmental stability. Given that this lineage of work was “carried out mainly by physicians and microbiologists whose agenda was primarily to reduce pathogenesis to physico-chemical terms” (that is, to find the source of disease), the motivation was pretty pragmatic and instrumental (Falk 2009: 191). A mutation in a single gene of the bacteria, it was found, could cause a pathology that killed the whole lot of them.¹⁵ Nevertheless, two important points stand out here. One is the obvious attempt at reducing biological phenomena to physical and chemical terms, which was in keeping with the defining character of molecular biology. The second, and the more important point that we wish to foreground, is how knowledge in a particular scientific field often comes from very different motivations and questions that the result ultimately leads to. Both of these reminders are integral to the historical conditions underlying the discovering of the molecular gene as the basis of a new science of life. It cannot be denied though that there was considerable resistance from biologists about accepting a “stupid molecule” like DNA, one that keeps repeating itself mindlessly and as such whether the latter could form the basis of explaining complex problems of heredity and development, as indeed the phenomenon of life (see Falk 2009: 194; Mukherjee 2016: 137). It is in this spirit that Muller-Wille and Rheinberger have pointedly commented that the new empirical sciences, of which the life sciences occupy a significant position, are often characterised by “the coincidence of incremental decisions rather than on the basis of deliberate revisions” (Muller-Wille and Rheinberger 2012: 184).

The Genetic Code and its Limits

At any rate, it was clear by the mid-1940s that the relation between DNA and cell function was meant to refer to the process of translation of genetic material into proteins or enzymes. It was also known that both DNA and RNA were long string-like molecules

¹⁵ This ‘one gene-one enzyme’ hypothesis, as formulated in the early 1940s, would later be refuted by further developments in molecular genetics, specifically when the structure of DNA would be elucidated and genetic regulation understood as a complex program in the organism. However, the mechanism that the hypothesis suggested was largely correct as the gene can be “visualised as directing the final configuration of a protein molecule” (see Mukherjee 2016: 163).

with four components or bases - the former with adenine, guanine, cytosine and thymine (or A,G,C,T) and the latter differing from the former only by switching thymine to uracil, thus abbreviated as A,G,C,U (see Mukherjee 2016: 135). But then, precisely because its structure was still obscure, “it was impossible to establish a logical relationship between the chemical nature of the gene and the mechanism by which the gene acted as the vehicle of inheritance” (Magner 2002: 436-37). This gap in knowledge was finally overcome by the collaborative efforts of Francis Crick, James Watson, Rosalind Franklin and Maurice Wilkins (even as the collaboration was not voluntary) in their three-dimensional model of DNA.

Much has been said about this discovery, both by its participants and commentators. We need to note, however, some essential insights that lead to the momentous event in the history of biology, and science in general. The structure of DNA in the Crick-Watson model (as it came to be commemorated) was based on biochemical and X-ray diffraction studies of other scientists and represented as a double helical structure (Magner 2002: 437).¹⁶ The structure was notable for the pairing of bases with each other - Adenine with Thymine (A-->T) and Cytosine with Guanine (C-->G) - which existed in equal proportion within the molecule, thus providing clues for its “highly regular structure” as described by James Watson himself (see Mukherjee 2016: 159). What was also notable was the precise sequence of bases in the long chain like structure that allowed for multiple permutations, becoming the source of variety in the individual organism (Falk 2009: 195).

Evidently, the structure of the DNA molecule was also an elucidation of its function, that is to say, “to see the DNA is to immediately perceive its function as a repository of information” (Mukherjee 2016: 157). Furthermore, the properties of both stability and variation were mentioned in the paper published by Crick and Watson in 1953, which also called attention to how the model can demonstrate a copying mechanism as well as

¹⁶ The biggest clue of the double helix shape instead of a single strand of DNA molecule came from Rosalind Franklin’s X-ray diffraction image, now popularly remembered as Photograph 51. The controversies that are intrinsic within the scientific plagiarism of Watson and Crick in presenting their model of DNA has also been written about widely (see Mukherjee 2016).

spontaneous generation through the occasional change in the sequence of bases while in the process of copying and thus causing a mutation. In the next few years, accordingly, the impetus of the biological community would be to experimentally show the validity of the replication mechanism that had been suggested in the structure of DNA (see Keller 2000: 52). By the late 1950s, Crick would be satisfied enough with the emerging scientific evidence on how DNA encodes information and controls cellular activity to establish the (mark the phrase) ‘central dogma’ of biology (ibid.). Within this singular phrase lay the roots of new knowledge as well as future determinism, suggesting a one-way movement to the effect “DNA makes RNA makes proteins that make us” (Crick 1957, as quoted in Keller 2000: 54). In the course of another decade, DNA would be referred as the ‘Master molecule’, setting it apart from other molecules (Keller, ibid.).

More insistently, it was this one-way flow of determination from DNA to RNA to protein to life that came to be hailed as the ‘code of life’, and its wide acceptance established the “precocious simplicity” of the new molecular genetics, if only for a short period (see Rheinberger 2000: 228).¹⁷ In keeping with this trend the theory of a genetic programme as put forth by Francois Jacob and Jacques Monod in 1959 was both an extension of the molecular vision and “the first wrinkle on the face of the central dogma” (Keller 2000: 55). It was an extension in the sense that Jacob and Monod had contextualised the action of the gene in the entire genome by pointing out that there were ‘structural’ genes that synthesised proteins to make an organism and these genes were in turn controlled by the ‘regulator’ genes (ibid.). Alternatively, it was a challenge to the central dogma inasmuch as it postulated the logic of circularity through the term ‘programme’ by asking how genes were expressed in the first place. This circularity is manifest in the idea that a gene does not just act on its own, but must be activated, and it must be activated by an ‘operator’ within the genome that does not itself encode for proteins.¹⁸ What is more,

¹⁷ In a manner of speaking though, hailing DNA as the ‘code of life’ continued till the successful completion of the Human Genome Project (1990-2003), with the latter essential for formulating its promissory language in other metaphors such as ‘reading the book of life’ (Rose 2007: 45) or decoding the ‘secret of life’ (Keller 2000: 7).

¹⁸ The term ‘operator’ came from what Jacob and Monod had termed the ‘operon model’ within the bacteria *E. Coli*. Keller helpfully clarifies: “The term operon refers to a linked cluster of regulatory elements and structural genes whose expression is coordinated by the product of a regulator gene situated elsewhere in the genome. ... The term operator refers to yet another genetic element, one that is equally critical to

this logic of circularity is also gestured in “the influence that cybernetics, modern communication technology, and the computer sciences had on [Jacob and Monod’s] new interpretation of the organism” (Muller-Wille and Rheinberger 2012: 185).

All the same, the term ‘genetic programme’ had made the whole genome a site of action, complicating the singularity and fixity of a gene in the notion of ‘gene action’ (Keller 2000: 57). Alongside, it also challenged the narrow hypothesis of one gene synthesising for one enzyme and thus resulting in one function. With this axis of knowledge, finding the gene for a particular character or pathology was realised to be a much more complex practical problem, besides having implications for the conceptual problem of defining and characterising genes through their networked function. Accordingly, as Keller demonstrates in her incisive questions: “Does the word ‘genetic’ refer to the subject or to the object of the program? Are the genes the source of the program, or that upon which the program acts?” (ibid.: 87).

A further limit to the genetic code was posed around 1970 through the discovery of transcription and the active role of RNA in building genetic information (see Keller 2000: 59). This was a concomitant of deeper investigations into the structure of the genome, entailing that the complexity of the most fundamental parts of life manifested themselves through the process of transcription which tended to move in phases. Indeed, even as the function of RNA was discovered in the making of genetic information, the gaps in the genome (later called “junk DNA”) meant a further questioning of the efficacy of the genetic code and the gene itself. Clearly, rather than a linear construction of information (DNA to RNA to proteins), there were different transcripts of the code. This, as Keller insists, was a major finding (ibid.: 60), and its active role was further foregrounded after the Human Genome Project “making redundant the one gene equals one protein model” (Atkinson et al. 2009: 3). In other words, any conception of a pre-given instruction or information was seriously challenged; rather, the constitutive instruction/information

regulation even though it has not yet been called gene” (Keller 2000:57). These linked clusters would become the basis of posing the question ‘what is a gene?’ within the paradigm of molecular biology.

comes to be constructed in the process of an organism's developmental stages (Keller 2000: 60-61).

III. Beyond the Gene: From Classical Genetics to Modern Genomics

The '*genetic code*' as a signifier had come to dominate the discourse of molecular biology, in contradistinction to '*message*' as a dominant signifier for classical genetics (see Mukherjee 2016: 160, emphasis in original). However, even as challenges to the central dogma were mounting in experimental research towards the end of the 20th century, molecular biology was also opening out its space of inquiry towards the whole genome. It became imperative to look deep into the sequence data of whole genomes of organisms to truly account for the complexity in the functioning of the organism. This increase in complexity, as scholars have argued, culminated in the shift from classical genetics to modern genomics. Indeed, as Barnes and Dupre assert, the shift from genetics to genomics can be seen as "a shift in our knowledge; that is, a shift in concepts, theories, and representations" (Barnes and Dupre 2008: 7).

Conceptually, this shift signifies a change in the very problem-space of research. If classical genetics took its problem to be the inheritance of invisible difference in the movement from one generation to another, modern genomics situated its problem to study the larger "chemical-molecular" system located inside the cell (Barnes and Dupre 2008: 8). Indeed, in approaching the problem in this milieu, modern genomics has been more inclined to study the 'normal' functioning of the cells and organisms. More pointedly, in this altered conceptual space, as Barnes and Dupre overall maintain, the dominant frame of heredity and descent within which classical genetics had unfolded has given way to that of an organism's whole life cycle to take account for such things as gene expression within an organism or a population. In due course, the problem of gene expression has also given way to the phenomenon of interaction between the gene, organism and environment.¹⁹

¹⁹ This interaction points in the obvious direction towards developments in epigenetics, or the study of what is now called the 'epigenome' (see Rose 2007 *passim*; Barnes and Dupre 2008). Epigenetics has its

The continuous problematisation of the gene itself has led scholars to argue that different conceptions of the gene proliferate even today. Griffiths and Stotz (2008), for example, argue that the continuity of different notions of the ‘traditional gene’, the ‘epigenomic gene’ and the ‘nominal gene’ is testimony to the fact that the gene continues as a useful model in research even as it has lost its boundedness. Likewise, in Rose’s (2007) overall assessment of the knowledges that followed from the Human Genome Project, the gene as the ‘blueprint of life’ has lost its efficacy in understanding organisms. Rather, as he accurately suggests, there is a shift in biological and biomedical languages from the stasis of the gene to processes of regulation, expression, transmission and transcription. Evidently, for him, life as information, even as shaping the new epistemology of biology, may not entirely be able to replace ‘life as organic unity’ (Rose 2007: 45).

Empirically, then, it was certainly from within the framework of molecular biology that serious efforts to understand the organism from its genetic information had taken shape. Strangely enough, often characterised as a project with a reductionist aim (see Morange 2008), critical analyses have stressed on the fact that the aim of molecular biology was a move towards materialism (see Rheinberger 2000: 226) or ‘molecular-structural’ modes of representations (Barnes and Dupre 2008: 48). Certainly, molecular biology - and one may extrapolate to the whole of biology as well - is not a science that can be axiomatised because it deals with the fundamental properties of living beings who are more than physical matter. In fact, these fundamental properties were what Jacques Monod (1970) had referred to as ‘chance and necessity’. The historian of science Rheinberger has thus argued with some foresight:

We have come a long way with molecular biology from genes to genomes. There is still a way to go from genomes to organisms that will need the efforts of a new generation of molecular developmental biologists, and the path from there to populations and communities, and vice versa, will not be shorter and left for still another generation (Rheinberger 2000: 232).

own history which was simultaneous to that of molecular biology but is coming into mainstream discourse only now with applications of post-genomic technologies.

All in all, we observe an interaction of life at these different levels, an interaction that molecular biology had traced back at the deepest level even as it drew the limits of that determination. Indeed, in our contemporary times, it perhaps makes sense only to talk of a flexible ‘dynamics’ of the genome so as to frame the problems of evolution, development and biological meaning (see Keller 2000: 31; Rheinberger 2000: 231). However, we can still say that the multidimensional study of vitality itself is a source of immense power for human beings, even as they form a part of the sphere in which life exists as association and interaction (the logic essentially of encounter) Our next chapter will thus be devoted to grasping the implications of this power – a postgenomics, really - as exemplified in the burgeoning space of biomedicine, which is in keeping with Mukherjee’s all-too-contemporary observation that today “organisms endowed with genomes are learning to change the heritable features of organisms endowed with genomes” (Mukherjee 2016: 12).

Chapter 4



Between Modern Genomics and Biomedicine: Compounding the Grounds

In the new field of biopolitics, where interventions are scaled at the molecular level, biology is not destiny but opportunity - to discover the biological basis of an illness, of infertility, of an adverse drug reaction in a cascade of coding sequences, protein syntheses, and enzyme reactions is not to resign oneself to fate but to open oneself to hope (Rose 2007: 51).

We must instead redefine what it is possible to think and how it is possible to live together (Reardon 2017: 201).

The historical epistemology of the gene, as rendered in the previous chapter, was located as part of a crucial trajectory in the discipline of biology where it (the gene) came to stand in for life itself. The shifting epistemic bases of biology in analysing this ‘unit of individuality’, as it were, underscore a significant relationship between concept and method as they are produced together in the very practice of science. Indeed, within an expansive history of scientific concepts and methods interrogating into questions of life, both before the formalisation of biology and after its inseparability from the physical sciences, we attempted to specifically understand how life and biology itself came to be molecularised through an epistemology of information in the contemporary era. This informational epistemology was most significantly constituted, as we duly noted in the previous chapter, by hailing DNA as a ‘master molecule’ and establishing the one way determination from DNA to RNA to protein to life as the ‘central dogma’ of biology or the ‘code of life’ (see Keller 2000; Rheinberger 2000). Equipped with the same understanding and techniques, the limits to the central dogma were drawn once it was realised that the DNA molecule by itself cannot determine all the information that constituted the organism. It was rather a much more complex picture that came to be highlighted with a move away from the sequence hypothesis of ‘DNA makes RNA makes

protein’ to processes of translation and transcription, thereby undercutting the possibility of any linear flow of biological information. The question suggests itself about how this undercutting was itself made possible. To put it more accurately, through what institutional and technological apparatuses were life, gene and information problematized, rendering them in an uncertain field of science maintained by the generation of ever more empirical data? The initial part of this chapter will seek to lay out this technological apparatus that drew the limits of genetic determinism, and in the process opened the gene to ‘postgenomic’ complexities and uncertainties.

We must hasten to add that these complexities and uncertainties have been, in the course of this dissertation, foregrounded from both a scientific and social scientific perspective. From the scientific perspective, as demarcated in the previous chapter, the term ‘new biology’ gained significance with the birth of molecular biology from the 1930s onwards. Its use however continues in what scholars (including the scientists working on the Human Genome Project) had recognised as the ‘postgenomic’ age of the 21st century (see Keller 2000; Rose 2007; Lock and Nguyen 2010; Reardon 2017). The Human Genome Project (HGP), as a collaborative research enterprise extending through the period 1990-2003 and whose aim was to map and sequence the totality of DNA in the human genome, acts as a kind of boundary event in such a characterisation of the contemporary moment, thus standing at the very cusp of old certainties and new uncertainties. Being *post-genomic*, however, does not only encompass a problematisation of the science itself, or even of understandings of gene, genome and the interactive processes of life; it is also supposed to capture a wider condition in which science, technology, politics and ethics become deeply enmeshed as genomics participates in what we can term as ‘vital process in social life’. In such a condition, we witness what scholars in science and technology studies (see Sunder Rajan 2015 and Hilgartner 2017, each following in the wake of Sheila Jasanoff 2015) have recognised as the ‘co-production of science and society’. Indeed, in Jasanoff’s description, ‘co-production’ functions as an ‘idiom’ of modernity, in turn a site for ‘sociotechnical imaginaries’ defined as “collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared

understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology” (Jasanoff 2015: 4).

Within the wider worlds that the postgenomic age lays down for socio-political and ethical evaluations – in fact, contours that a single chapter cannot possibly encompass - we shall concentrate on certain specific domains in which modern genomics has made its presence felt the most. Crudely, it would not be inappropriate to assert that modern genomics gains its most relevance within the field of contemporary biomedicine. Social scientists have from the last few decades of the 20th century explored the transformations in biomedicine and contemporary societies as mediated by the application of new genetic technologies (Atkinson et al. 2009: 1). Pointedly, the literature produced by the very architects of the HGP as well as the many post-facto analyses of bioethicists, social scientists and historians place much emphasis on the promised changes in biomedicine as conceived before and after the project. Following from this, we shall go on to ascertain the terms of some prominent issues in the biopolitical field in which ‘subjectivity’ comes to be reshaped at the intersections of technology, politics and ethics. The latter ground will serve as a demonstration of the deeply political and ethical role that genomics has come to play in the interactions of human lives with the more-than-human milieu in which they exist (Savransky 2016: 7).

I. Genomics and Postgenomics as Distinct Imaginaries

In referring to the contemporary and emergent genomic and postgenomic tools of scientific research, Lock and Nguyen postulate how they have been successful in ‘dethroning the gene’ and thus in rendering unstable our ‘logics of vitality’ (Lock and Nguyen 2010: 331). This deposing of the gene, as the medical anthropologists’ recount, was enabled by the eclipse of the era of genotype-phenotype distinction which had privileged the language of DNA, and had its culmination point in the HGP (ibid.). What followed from the project was what we shall go on to term as ‘postgenomic complexity’, whereby DNA is no longer considered the sole arbiter of life or vitality. In an alternative rendering, Maurizio Meloni terms the era of genotype-phenotype distinction as that of

‘hard heredity’ which strictly demarcated the “ontological domains of the biological and the social, nature and nurture, and the life and the social sciences” (Meloni 2016: 2). In the contemporary postgenomic era, on the contrary, hard heredity has been replaced by the notion of ‘soft heredity’ whereby the relation between the genotype and phenotype, or DNA and protein as part of cellular mechanisms, cannot be strictly unidirectional or even simply separate.

Following Jasanoff (2015) and Hilgartner (2017), we extend the idea of ‘imaginaries’ in defining the terms ‘postgenomic’ as distinct from ‘genomic’. In fact, Meloni (2016) delineates five different meanings of the term ‘postgenomic’, synthesising them from the works of several commentators on the following grounds: chronological, infrastructural, methodological, political-economic and conceptual. Where ‘chronologically’ postgenomic can only refer to the period after the human genome sequence was put out in the public domain, on the ‘infrastructural’ front it came to refer to a broader category of biological research with approaches framed as “omics” that “extend the existing genomic programs and paradigms across the many subfields of the life sciences” (Meloni 2016: 192). Other than the genome, these emerging ‘omics’ began to include such biological entities as the proteome, microbiome, transcriptome, epigenome etc., each the inhabitants of the ‘molecular environment’ of the body. The infrastructures of these new ‘omics’ fields are also closely tied to the highly data-driven ‘methodologies’ of sequencing which include large scale maps and digital databases. Indeed, closely bound with the infrastructural and methodological aspects of postgenomics is its ‘political-economic’ landscape, largely functioning within a neoliberal regime of governance. Participating in a ‘commercial structure’ of speculative finance, postgenomics (as Meloni underscores) works with neoliberal ideas of the self, like self-optimisation and individual risk (see also Rose 2007; Lock and Nguyen 2010). Lastly and more immediately, postgenomics has ‘conceptually’ turned to foregrounding “unanticipated levels of biological complexity” (Keller 2015: 16) and thus may imply “going beyond the genome, as we know it” (Meloni 2016: 193). These meanings surely do not stand apart for there is considerable overlap in the styles of reasoning embodied across the space of modern genomics and its wide-ranging fields of application.

Genomic Era: Claims of Neutrality, Free Information and Democracy

In 1990, the National Institutes of Health (NIH) and Department of Energy (DoE) in the United States of America led a collaborative project involving scientists and technicians from multiple countries to sequence the first human genome. Drafted as a culmination of the sequencing efforts of molecular biologists to decipher the genomes of several lower organisms, the Human Genome Project (HGP, as it was named) had begun as a public project designed after, and often compared in its scale with, the Manhattan Project that resulted in the making of the atomic bomb (see Hilgartner 2017: 222; Reardon 2017: 25). But as Mukherjee (2016) and Reardon (2017) make clear, the two projects were linked historically, and not just metaphorically, with one of the originary visions of the HGP coming specifically from the U.S. Department of Energy which wanted to assess the effects of mutations caused by radiations from the atomic bombing. Indeed, as Reardon declares in this context, the project was born out of “problems of knowledge and justice produced by the ghosts of the atomic age” (Reardon 2017: 25). All the same, an equally important motivation behind the HGP was to map the genes linked with genetic diseases by isolating the part of the genome in which it can be found (Mukherjee 2016: 295). It was also, since its beginning, immersed in the political and ethical consequences that such an initiative may hold, one that was formalised in the creation of the ELSI (Ethical, Legal and Social Implications/Issues) Programme, established in 1990 with an allocation of 5 per cent of the total budget of the megaproject (see McEwan et al. 2014). We shall assess the research within the ELSI programme in a later section, but for now, one can suffice to say that the HGP did not entirely fall into any simple categorisation where the social was opposed to the biological, or the life sciences separated from the social sciences.

Nonetheless, one may observe a distinct imaginary in what Mike Fortun (2012) has called the ‘promissory language’ of genomics in which the project was publicised, specifically in the discourse of information and how it should be made available to the public. Fortun describes promises as “performative speech acts” and as “forward looking statements” that structure language (Fortun 2012: 331 and 335). Indeed, the HGP, as Reardon puts

in perspective, was fundamentally rooted in the Enlightenment notion that free and equal access to information is the cornerstone of a democratic, rational and just society (see Reardon 2017: 8). Not unexpectedly, the human genome was hailed as the “hieroglyph of biology”, the “biological information” itself (Sulston and Ferry 2002: 8), “the book of life” and “the vision of the Grail” (Rose 2007: 45-46) by its various leaders. It was central to their vision of an ‘ethic of communism in science’ (Reardon 2017: 29), that is to say, to make this information par excellence freely available in the public domain for its benefits to reach society. The ‘book of life’ was supposed to belong to “every member of the human race” (Palsson 2007: 154) and not just a few individuals in the Western liberal world. In the mid-1990s, however, this vision of science as a communal good was temporarily disturbed by the biotechnologist Craig Venter who not only claimed to produce the complete sequence of the genome within a shorter time, and at a much lesser cost than the public project, but also planned to make profit by selling the information to pharmaceutical companies and making it open to patents (see Palsson 2007: 153). This ‘genome war’ (ibid.: 152-157) which involved public leaders making and using various performative claims against the threat of privatisation of genetic information has been memorialised in many popular accounts of the HGP.¹ It may suffice here to say that within the imaginary of genomics, the promise of science as a communal good was inseparable from a discourse of understanding where more information meant more democracy and thus more knowledge for the people.

However, holding onto the communal ethic of science did not last long as the looming reality of the ‘technological landscape’ (Kay 1993), questions of ownership (Reardon 2017) and the inevitable participation of private biotechnology companies came to be recognised and confronted by the leadership of the project. In such a scenario, it was inevitable that the performative speech acts in publicising genomics came to be slightly

¹ The ‘genome war’ would perhaps become the most publicly written about account of public-private competition to achieve a breakthrough in the experimental sciences of biology. However, from Mukherjee’s (2016: 238-43) account of developments in gene cloning and sequencing, one can extrapolate that the race to sequencing the human genome was not the first race in the history of new genetics, or new biology. With the era of biotechnology opening out the possibilities of new genetic technologies, successful developments were driven by the public and private institutions to clone and synthesize genes outside their natural environments, and this had been going on since the 1970s.

revised. Thus, in June 2000, the public announcement of the completion of the first draft of the human genome - the event whose excerpts were published in a *New York Times* (*NYT*) article titled ‘Reading the Book of Life’² - was jointly coordinated by the then U.S. President Bill Clinton, the U.K. Prime Minister Tony Blair, the biotechnologist Craig Venter, and leader of the HGP, Francis Collins. Clinton famously ended his speech by affirming belief in the “public-private cooperation” and acknowledging the “robust and healthy competition” (as reported in the *NYT* of the day) through which the draft of the human genome could be finished before planned. As the drafts created by both the public and private efforts were published in the journals *Nature* and *Science* respectively, it seemed inevitable for the leadership to accept the role of private biotechnology companies to “bring to the market the life-enhancing applications of the information from the human genome” (*NYT*).

Interestingly yet, President Clinton had retained the language of genetic essentialism and theology when he compared the human genome to the “language in which God created life” (*NYT*), invoking the mechanistic religious point of view of the 17th century which famously claimed that Galileo had found, through his mathematical theorems, the language in which God created the universe. Alternatively, comparing the genome to the founding map of the Americas, the project of mapping the human genome had become a cartographic exercise of taking a passage into the “remotest corners” of the living organism (Palsson 2007: 32). Indeed this language of cartography had also linked directly with the colonial enterprise of travel and discovery into unknown parts of the world and constructing objective knowledge of it. Thus, as with the colonial exercise, human activities like traveling and mapping are hardly neutral or innocent in their ways of knowing (*ibid.*: 50). Genetic maps equally act as what Palsson calls ‘performative constructs’ while “bringing genes into existence ... making them manipulable, mobile and assemblable” (Palsson 2007: 56). The feminist philosopher of science Donna Haraway even likens the technoscientific practice of gene mapping with cultural practices

² See <https://www.nytimes.com/2000/06/27/science/reading-the-book-of-life-white-house-remarks-on-decoding-of-genome.html> (Last accessed March 31, 2019). The citations that follow in this paragraph and in the first sentence of the next paragraph are from this source, as acknowledged.

that should be read as historically specific forms of spatializing the human body, modalities that are not purely technical or representational but are gathered together by “institutions, narratives, legal structures, power-differentiated human labour, and much more” (Haraway 2000: 116). In the same vein, any equivocations of the genome with life itself had to be historically specific and came to be rendered problematic in due course of time.

Postgenomic Complexity: Interpretation, Automation and ‘Omicisation’ in Biology

The completion of the HGP in 2003 had rendered true Evelyn Fox Keller’s insightful observation that the successes of the project had “radically undermined [its] core driving concept, the concept of the gene” (Keller 2000: 5). To elaborate on her statement, when the HGP was being conceptualised in the 1980s, molecular biology had gained widespread currency within the discipline (as was also duly noted in the previous chapter). The translation of life as information, itself following from the cybernetic approaches of the Second World War era, had entailed working with the problem of encoding information accurately (see Reardon 2017: 41). However, for HGP scientists, the goal of the project since its very beginning was to ‘decode’ genetic information, to decipher its meaning. In their imaginary, they thus worked with what Reardon classifies as the ‘modern’ idea of information, which is to understand its meaning. One can gather that such a difference between encoding and decoding became evident even in the working years of the project from John Sulston’s account of HGP, recalling his experiences of being one of the public leaders of the project. In his position of heading the U.K. wing of the project, Sulston had claimed that humans would possess the “hieroglyph of biology” after having ‘decoded’ the human genome (Sulston and Ferry 2002: 8). Yet he was quick to immediately qualify that interpreting the information would take a long time and involve the efforts of the “whole biological community” (ibid.). This was because with the first draft of the human genome published in 2000, scientists had realised that only ‘sequence information’ was not enough for them to either decipher the “program that makes an organism” or to grasp biological function (see Keller 2000: 6-7). In the post-HGP focus on functional rather than structural genomics, Keller notes that one can read a “tacit acknowledgement of how large the gap between

genetic ‘information’ and biological meaning really is” (ibid.: 8). Accordingly, bringing out the uncertainty of the new life sciences, Keller sharply suggests that this gap was precisely what enabled “marvelling not at the simplicity of life’s secrets but at their complexity” (ibid.).

To be sure, the gap between ‘sequence information’ and ‘biological meaning’ was dependent, in large part, on two interrelated changes in the practice of a technoscientific field like genomics. One was the turn to automation in genome sequencing (see Reardon 2017), and the other was the expansion of genomics to other ‘omics’ disciplines (see McNally and Glasner 2007). Shifting from an ‘analogue’ to ‘digital’ approach and aided by large sequencing machines and supercomputing technologies, HGP leaders believed, would bring out the “empirical facts of life” objectively without human intervention and error (see Reardon 2017: 41-42). However, the digital approaches led to further challenges, underscoring the fact that sequence information alone could hardly have any meaning or value for either scientific knowledge or public welfare. It is precisely for this reason that Reardon defines the ‘postgenomic condition’ as “the turn to the question of meaning, that is, the question of the uses, significance and value of the human genome sequence” (ibid.: 2). Not surprisingly, the tools of automation seem to have rendered scientific knowledge problematic in the postgenomic era as it becomes harder to distinguish between the work of humans and machines in producing knowledge. Indeed, the endeavour to use computers as a means of freeing humans “to work on the more interesting and difficult biological problems” (Reardon 2017: 199) has been shrouded in doubt as the centrality of computers in genomics may be changing the very nature of biological practice. This involved a change in the way scientists carried out their work, particularly the communal ethics shared by the HGP leaders, and in a sense giving way to their fears of private control of genetic information (ibid.: 36). In fact, in postgenomic times when the task is that of interpreting sequence data, it is realised that automation has not guaranteed complete success as biologists remain unsure of the protein-coding regions in the genome (ibid.: 198). Not surprisingly therefore, Reardon remains rightly sceptical about the bias towards automated approaches insofar as they may influence our knowledge of the genome for the worse.

Paradoxically, this move towards automation also leads scientists to move beyond the genome. The primary promise of genomics, as already noted, was that once the entire genome is sequenced, any disease with a genetic basis can be linked to its underlying sequence information and at a rapid speed (see also Mukherjee 2016: 294). This was supposed to be applicable for both single-gene disorders (also known as Mendelian disorders) and ‘genomic illnesses’ that are not dependent on a single gene but need to be recognised by understanding the relations between multiple genes (ibid.: 295). Since understanding a gene (or rather a ‘DNA sequence’) was impossible without understanding its molecular counterparts like the protein, there was a move away from DNA to processes of transcription, regulation and expression that came to be known as ‘transcriptomics’, and from the gene to the whole cell and the process of creation of proteins, which was studied as ‘proteomics’ (see Rose 2007: 46). Rose also lays out how a call towards complexity was existent during the years of the HGP, as in Craig Venter’s suggestion to abandon the reductionist approach in favour of models of complexity in human biology that explores ‘networks’ that exist at various levels of organisation.³ In this context, clearly, modern genomics had become more of a “methodological revolution” than a theoretical one both for biology and biomedicine (see Atkinson et al. 2009) with similar approaches of upscaling, large scale data-collection and their digitisation being used for other biological entities.

Similarly, Ruth McNally and Peter Glasner (2007) have written of the shift from the ‘century of the gene’ to the new ‘omics’ era of research in biology. Highlighting that the suffix ‘ome’ in words such as the ‘chromosome’ is supposed to refer to the collectivity of units in a biological system, they underscore a conceptual and methodological ‘omicisation’ of all entities of biological and biomedical research (McNally and Glasner

³ This line of thinking both stems from and has given shape to the development of ‘systems biology’, a science which (in the words of its contemporary practitioners) attempts to view life through a renewed thinking “in terms of relationships, patterns, and context” (Capra and Luigi Luisi 2014: xii). The genealogy of ‘systems thinking’ in biology is also located in the conceptualisation of life between mechanism and holism (or vitalism), which further served to shape the route of molecular biology. We traversed some aspects of this ground (without necessarily implicating systems biology per se) in our Chs.2 and 3 above.

2007: 255). This style of research, even in the eyes of HGP leaders, went outside of the strictly biological realm, including in its wings the ‘omicisation’ of the social, the latter consisting in the collection and analysis of ‘sociomic’ data-sets on forms of social identification such as sexuality, ethnicity, race, behaviour, lifestyle etc. (ibid.: 263). Indeed relating the ‘biological’ with the ‘social’ data was the aim behind creating nation-based biobanks, which are largely digital databases that inquired into questions of relatedness and health of its citizens by combining genealogical and medical information (see Palsson 2007: 69).⁴ In this regard, complexity is not only becoming the condition of contemporary biological research, but for sociocultural research as well. In fact, the sociologists/anthropologists Lindee, Goodman and Heath (2003) privilege this attention to complexity, as genetics has entered into the domains of identity and its historicity and politics. They further affirm that anthropology cannot ignore the powers of this new science and its reconceptualization of both nature and culture (or, in other words, implicating the biological and the social).

Two related but inconsistent conclusions can thus be drawn with these routes of complexity between information and meaning. On the one hand, we have (in Rose’s framing) a scenario where “(a) genetic style of thought is giving way to a postgenomic emphasis on complexities, interactions, developmental sequences and cascades of regulation” undercutting the informational epistemologies of life (Rose 2007: 47). On the other, even as life itself “resists its reframing in terms of information”, it is largely stored as information (ibid.: 48) and accordingly transforming biological knowledge itself. Arguably, these two developments together mark the fundamental uncertainty of the postgenomic imaginary in which we live today. More pointedly, if there is no value neutral way for us to know the genome, and in the process know ourselves and the state of our health and illness, it becomes pertinent to ask about the ways in which this knowledge is being mediated in contemporary societies. We shall now move on to exploring similar uncertain consequences in the interrelations between genomics and

⁴ Some examples of such biobanks are the Heath Sector Database created by DeCode Genetics in Iceland, Generation Scotland, the Gene Bank Database in Estonia, and the Super Control Genomic Database in Taiwan (for cursory details on each of them, see Palsson 2007: 95-111).

contemporary biomedicine, especially with regard to forms of individual and collective identification.

II. Genomics, Biomedicine and Society: A Biopolitical Reading

Introducing their vision for the future of genomics, Francis Collins and his colleagues, on behalf of National Human Genome Research Institute (NHGRI), drafted a report titled ‘A Vision for the Future of Genomics Research: A Blueprint for the Genomic Era’ in 2003, soon after the completion of the HGP. Announcing their entry in the ‘genomic era’, the scientists’ underscored that “the challenge is to capitalize on the immense potential of the HGP to improve human health and well-being” (Collins et al. 2003: 836). The NHGRI had been exclusively created out of the National Institutes’ of Health in the U.S. so as to translate the “successes of HGP into medical advances” and to connect “its scientific research programme with research into the social consequences of increased availability of new genetic technologies and information” (ibid.). Consequently, in their vision for the future of genomics, the representatives of NHGRI regarded the HGP to provide a fundamental base on which genomics research and the data being produced can be of use, firstly, to biology, secondly for medicine, and thirdly for society. Represented in the diagrammatic figure of a building, the three domains were positioned hierarchically one above the other, all in turn resting on the base of the HGP. Given its policy orientation for the applications of genomics in health, the report announced its mission as not only creating a new ‘molecular taxonomy of disease’ to increase the accuracy of recognising disease susceptibility and charting out individual responses to drugs, but also to identify the gene variants that can contribute in maintaining good health (ibid.: 840-41). Such a vision of genomics and health, evidently, not only sought to standardise the pathological but also the normal state of human well-being, and thus can be analysed through a ‘biopolitical’ frame/approach.

One must recall Foucault’s definition of the ‘biopolitical’ at this moment, whereby both biological and social life as manifested by the individual and the collective become the object of politics. It is important to note that in Foucault’s understanding of biopolitics,

the process of the ‘subjectivation’ of human beings both in terms of the way they are made as subjects capable of creating knowledge and the way in which they become ‘subjected’ to power/knowledge were actually and analytically interconnected (see Cremonesi et al. 2016). Consequently, ‘biopower’ for him was a particular modality of government that differed from the sovereign state’s exercise of power, obtaining less by commanding the death of dissidents and more by ‘managing’ the life of its citizens in micro-practices of health, sanitation, birth, sexuality etc. so as to achieve the ‘subjugation’ of bodies and ‘control’ of populations (see Jasanoff 2011: 6). Even more pointedly, for Rose (2007), biomedicine and its political perception have brought about considerable changes in the way contemporary biopolitics has taken shape. He explicitly delineates five ‘mutations’ in contemporary biopolitical thought, which he renders as follows: (i) molecularisation of life; (ii) enabling technologies of optimisation, outside of the binaries of health and sickness; (iii) novel forms of individual and collective subjectification rendering humans as ‘somatic individuals’ and ‘biological citizens’; (iv) creating somatic experts like bioethicists; and (v) the making of a bioeconomy in the global market, capitalising on life itself (see Rose 2007: 5-6).

Even though biomedicine as a field combining biology, physiology and health predates the advent of modern genomics, scholars have employed the term ‘biomedicalisation’ to refer to the “technoscientific transformations in health, disease and identity” traced from the mid-1980s onwards when the biosciences and computer information technologies were built into the increased space of medicalisation in the U.S. and U.K. (see Clarke et al. 2009: 21). The HGP thus needs to be located in this context of biomedicalisation. These technoscientific transformations have opened the doors of new possibilities for human health, along with creating what Stephen Collier and Andrew Lakoff (2005) term specific ‘regimes of living’. Indeed, in their description of ‘regimes of living’, Collier and Lakoff argue that a particular understanding of ethics underwrites such contemporary situations, where the ethical does not only involve an ‘adjudication of values’ but also includes a practice and a subject of ethical reflection on the question ‘How should one live?’ (see Collier and Lakoff 2005: 22). These ‘regimes of living’ are thus presented to us as “a tentative and situated configuration of normative, technical, and political

elements that are brought into alignment in situations that present ethical problems – that is, situations in which the question of how to live is at stake” (ibid.: 23). Needless to say, scholars have debated vehemently on the political and ethical aspects of ‘regimes of living’ as created by contemporary biomedicine, especially with regard to the historical scandals of eugenics (see Rose 2007: 54-64, as also 226-29). However, following Atkinson et al. (2009), we should be conscious of overestimations in social scientific analyses that interpret contemporary situations either as entirely unprecedented or propagate a wholesale affirmation or rejection of the underlying values governing them.

Geneticisation of Biomedicine: Ethnographic Instances

To be sure, the new genetic technologies exploding in the market from the 1970s onwards have brought with themselves the fears of a ‘new eugenics’, triggering memories of a past coloured by the excesses of the Nazi state (see broadly Rose 2007 and Mukherjee 2016). These collective fears from the scientific and social spheres can be traced back to the time when the cloning of genes made it possible for biologists to read, write, copy and edit DNA. In fact, Mukherjee describes gene cloning or molecular cloning simply as “the entire gamut of techniques that allowed biologists to extract genes from organisms, manipulate these genes in test tubes, produce gene hybrids and propagate the genes in living organisms” (Mukherjee 2016: 222). Indeed, from the use of genetic engineering in creating pharmaceutical drugs through recombinant DNA technology in the late 1970s was born an industry of biotechnology and its clinical uses in the form of genetic screening and testing, gene therapy, pharmacogenomics and personalised medicine, overall forging an idiom of ‘potential’ to change our very genetic constitution (see Taussig et al. 2003). Some biotechnologies like gene therapy, pharmacogenomics and personalised medicine still remain embedded in the world of promises, but have created considerable hype in public discourse, especially as adverted during the years of the HGP.⁵

⁵ Particularly, the hype around gene therapy has also been met with serious condemnation in scientific and popular discourse after the death of an 18-year old patient Jesse Gelsinger in 1999 who was put on a clinical trial of gene therapy for a rare metabolic disorder that had been inherited in the womb. Famously remembered as the ‘biotech death’, the episode had spawned intensive debate in the community of bioethicists on the fatal dangers of medical intervention through gene editing. For details of the case, see Mukherjee (2016: 429-34) and the famous NYT article that coined the term ‘biotech death’

More specifically, the history of genetic screening and testing programmes in different parts of the world offer a context to evaluate some unclear boundaries between eugenics, optimisation and risk assessments. Their rapid expansion especially in the U.S. had led epidemiologist Abby Lippman to coin the term ‘geneticisation’ in the early 1990s to refer to a new kind of ‘medical surveillance’ in which individual differences are reduced to people’s DNA (see Lindee et al. 2003: 2; Lock and Nguyen 2010: 310). This opened the doors of possibility for discrimination against people with disabilities, and the propagation of a new kind of racism founded on an essentialised biology interacting with social realities (see Lock and Nguyen 2010: 310). Interestingly, however, ethnographic studies of genetic screening and testing bring out the heterogeneity of effects and affects that geneticisation entails for individuals as well as social groups.

The joint work of medical anthropologists Karen-Sue Taussig, Deborah Heath and Rayna Rapp (2003) among people with heritable dwarfism and their organisation named ‘Little People of America’ (LPA) comprising of medical experts and lay advocates is exemplary of such heterogeneity. Faced with options like prenatal genetic testing geared to identify if their offspring’s carry the gene for dwarfism, voluntary abortion, and controversial surgical interventions like limb lengthening, the members of LPA held diverse responses to each of them, while also holding on to some complex justifications. At least one ‘LP’ considered the option of limb lengthening as a form of optimisation, and not correction of their condition, while one physician considered it “abhorrent” and underscoring a continuity in denouncing both “orthopaedic and genetic interventions” (see Taussig et al. 2003: 64). Indeed, this multiplicity of attitudes towards intervention is what the scholars’ refer to as a ‘flexible eugenics’ involving “technologies of the self through choosing and improving one’s biological assets” (ibid.: 65).

The practice of such flexible eugenics has been foregrounded from the perspective of genetic counsellors as well, as in Rayna Rapp’s famous 2000 ethnography on the social

impacts of amniocentesis in the U.S. (see also Lock and Nguyen 2010: 311-13, for a summation). As a test for detecting Down Syndrome and other single gene disorders, the genetic counsellors carrying it out and communicating the results to the pregnant women are all supposed to be neutral ‘information brokers’ of rational knowledge. But then, being located in an ethnically and racially diverse region where class differences exist between women of White, African-American and Hispanic ancestry among others, genetic counsellors have the inadvertent power to propagate “stratified reproduction”, whereby women of some ethnic and class backgrounds are encouraged to reproduce while others are disempowered (see Lock and Nguyen 2010: 312). Significantly, Rapp in her extended ethnography also foregrounds the fact that the women’s own responses to the testing are culturally specific and diverse, structured according to factors ranging from cultural and scientific knowledge, family and kin relations, religious values to the environment of the testing clinic, the technicality of language on the consent forms circulated, their own evaluations of the test’s success rate in the past and the overall historical experiences of the community with medical interventions (see Rapp 2000). Clearly, in this over-determined context, there cannot be a simple ‘feminist’ response towards amniocentesis as either liberatory or socially-controlling because it can ‘*potentially*’ be both. What is important to emphasize is that this ‘potentiality’ is constituted both by the unavoidable biology of genetic responses and the sociocultural weight of one’s identity (as implied in both Rapp’s detailed ethnography, and the summation provided in Lock and Nguyen).

The potentiality of both liberation and social control, in the context of both genetic and non-genetic factors in the epidemiology of disease, is what leads Adam Hedgecoe (2001) to talk of the possibility of an ‘enlightened genetics’ rather than diagnosing all genetic research of medical conditions as opening the doors to racism and discrimination. Indeed, the ethnographic instances from genetic screening cited by Lock and Nguyen (2010: Ch.12 broadly) further support the heterogeneity of responses with regard to ‘geneticisation’ and its effects on people. Set against a backdrop of assessing susceptibilities towards particular genetic disorders that affect specific communities disproportionately, screening programmes in their design target inevitably a population

rather than an individual and moreover are differently institutionalised in local national contexts. Thus, for instance, contestations to the negative theorisation of geneticisation have come from the case of the screening programme for the Tay-Sachs disease affecting a sizeable proportion of the Ashkenazi Jewish community. Often referred as the ‘Jewish disease’ in popular discourse in North America, even as the genetic mutation is found to be affecting other communities as well, ‘genetic essentialism’ in this case can be seen as a mobilising factor that brings religious authorities (Jewish rabbis) and potential carriers of the disease in making marriage and reproductive choices. Some controlling factors in the face of the high stigmatisation against the community members is that the tested individuals are not told of their result directly; they are only free to know if their “potential union is ‘genetically suitable’” (Lock and Nguyen 2010: 320). Less information, accordingly, can be both a form of control as well as individual protection, especially in a situation where a recognisably orthodox community holds procreation essential, discourages abortion and possesses views of stigmatisation against a genetic disease.

Contrary to the positive response that members of the Ashkenazi Jew community have held towards the genetic screening programme are the “political struggles” of the African-American community against the compulsory screening programme for sickle cell anaemia in parts of the U.S. (see Lock and Nguyen 2010: 323-25). Exclusively associated with the Black community, the case of sickle cell screening highlights the negative consequences of genetic essentialism and stigmatisation as the programme was made mandatory from the mid-1970s to early 1980s for children to get tested before they entered school. Indeed, creating institutional conditions that proliferate stigma when there is no permanent cure for the disease and the community in question faces discrimination in the larger social life of the nation forms the context for what the African-American sociologist Troy Duster had famously dubbed as ‘the backdoor to eugenics’ in 1990 (ibid.: 324; also Reardon 2017: 52). The orders of this critique clearly meant that the screening programme worked with the explicit intention of ‘disposing off’ foetuses not only affected by the disease, but also those recognised to be ‘heterozygous’

(cases where only one parent carries the mutated gene) and in all probability would manifest no symptoms of it in their life.

Evidently, then, these multiple localised ethnographic instances of genetic technologies highlight the stratified ‘regimes of living’ that get created, involving considerations of ethnicity, nationality, and kinship intersecting with ‘institutional mediations of science and technology’ and accordingly testifying to the ‘coproduction’ of the social and scientific. In fact, debates on increased geneticisation, both before the HGP and during the duration of it, are today undergoing other mutations brought about by the postgenomic complexity as broadly recounted in the previous section. The negative characterization of geneticisation (or even ‘enlightened’ geneticisation) is now more than ever coming face-to-face with new uncertainties and complexities, especially given the pace of the technological reconceptualization of life that the contemporary moment entails. In this background, the ways of constituting the subject also undergo changes, if not epochal shifts.

Constituting the Subject: Risk, Citizenship and Creating Value

Obviously, the technologies of genetic screening and testing, as broached in the situations recounted above, highlight the tendencies of both individualising and collectivising human subjects under scientific categories. Indeed, they do so explicitly through calculations and diagnosis of risk for a genetic disease. The anthropologist-theorist Paul Rabinow has effectively proposed that “risk is not a result of specific dangers posed by the immediate presence of an individual or group, but rather the composition of impersonal ‘factors’ which make a risk probable” (Rabinow 1996: 100). Indeed, anthropologists and sociologists have focused extensively on the impersonality of risk assessments in modern times. Among the most prominent of such conceptualisations is Mary Douglas’s definition that underlines the transition from the language of ‘danger’ to that of ‘risk’ in the context of an expanding industrial world (see Douglas 1990). For Douglas, ‘risk’ was quintessentially modern because, unlike ‘danger’ that inextricably bound the individual with the community in its aim to protect the latter, risk is often about protecting the individual from the other. Even as there may be no actual difference

between the two other than the way they are politicised, the language of ‘risk’ (as Douglas rightly avers) attains a rhetorical effect of neutrality and scientific legitimacy.

Significantly, even as this rhetoric of neutrality and scientificity remains true for both genomic and postgenomic landscapes, the individualising tendency of risk has been seriously contested. As evident in the various ethnographic instances of genetic screening and testing, and following from Rabinow’s proposal, the calculative practices of risk in genetic research hardly discounts community ties and even leads to the formation of new group identities like that of the ‘Little People of America’ (LPA). More poignantly, such groups constitute the realm of ‘biosociality’ in which social relations are organised around the new biological truths as created by science. These biosocial groups “whose members meet to share their experiences, lobby for their disease, educate their children, redo their home environment and so on” (Rabinow 1996: 102) accordingly represent forms of ‘biopolitical activism’ (Lock and Nguyen 2010: 310). To be sure, many such groups existed even before the turn to the new genetics, with some being ostensibly ‘anti-medical’ and oriented to opposing the over-medicalisation practiced with respect to some communities as exemplified in the history of the Black population (see Rose 2007: 134). However, the shift from ‘danger’ to ‘risk’ as individualising can make sense when one thinks of risk as embodied and, more poignantly, with genetic mutations as embodied risks that have the potential of actualising in the future. Such an understanding of ‘embodied risk’ has also led to the constitution of the genetically-at risk subject - a product essentially of biomedical authorities - who is supposed to be engaged in an active care of the self and maintaining a sense of ‘genetic responsibility’ not only towards themselves but also towards their kin (see Rose 2007: 124-25).

Extending the terms of the discussion, Nikolas Rose and Carlos Novas (2005) have sought to locate Rabinow’s theorisation of biosocial communities and the constitution of the genetically at-risk subject as the two poles of the collective and the individual respectively on which the phenomenon of ‘biological citizenship’ can hinge. Recognising citizenship, and not just the state in the political history of identification, Rose and Novas testify to the emergence of this new kind of citizenship in the age of

biomedicine, biotechnology and genomics. ‘Biological citizenship’ accordingly, in their rendering, includes projects that have “linked their conceptions of citizens to beliefs about the biological existence of human beings, as individuals, as families and lineages, as communities, as population and races, and as a species” (Rose and Novas 2005: 440). They maintain that the techniques of contemporary ‘biological citizenship’, broadly paralleling those of the eugenic models of the early 20th century, are designed around the ‘management’ of the hereditary stock of their population, as it were. However, a crucial point of difference has to do with the fact that the objectives of contemporary biomedical authorities, both at the level of the state and non-state, are not so much concerned with maintaining racial purity, but with the hope that specific biological (or genetic) characteristics of groups of citizens can be turned into a valuable resource via biotechnological innovations (ibid.: 444).⁶ It is in this context that the ‘burden of genetic diseases’, often seen as sources of drain on the health of a nation’s population and its medical services, are being turned into “potentially valuable resources” (ibid).

It is thus understandable that, in their elucidation of ‘biological citizenship’, Rose and Novas call attention to the context in which citizens come to understand themselves in a biological language - as mediated by public disseminations of health education and medical advice (of which the internet plays a crucial role) - and to situations where the “citizen’s own vitality is at stake or that of those for whom they care” (Rose and Novas 2005: 446). Actively participating in what is termed a ‘political economy of hope’, biological citizens become political in the process of becoming consumers of the technologies that they hope would rid them (or anyone they care for) of their burden. However, in situating the concept of biological citizenship within these contexts, Rose and Novas also limit its applicability to certain populations in advanced liberal economies and national contexts, specifically to those who have the needed educational background and economic resources to become biopolitical activists and consumers.

⁶ As a prominent example of national genetic citizenry being turned into biomedical research subjects, the authors’ cite the case of the Finnish population that for its genetic peculiarities has served as the model gene pool for research into genetic susceptibilities to disorders like schizophrenia, manic depression, alcoholism etc. (see Rose and Novas 2005: 444).

Importantly, in an effort to sound the limits of the foregoing discussion on subjectivity as constituted at the intersection of biomedicine and genomics, we must open up to the counterpoint of the ‘experimental subject’ as posited by Kaushik Sunder Rajan (2011). Against an elaboration of the agential, self-moulding subject in the process of becoming political, Sunder Rajan attempts to come to terms with an always-already created subjectivity as situated in particular historical and cultural contexts and thus differentially constituted in different parts of the world. Through his comparative ethnographic work on two genomic pharmaceutical companies in California, U.S. and Mumbai, India, Sunder Rajan explores the intricate circuits of global economy in which infrastructural capacities are being built for genomic medicine, especially with first world economies outsourcing clinical trials to employ the third world subject’s ‘experimental body’. While the advertising for direct-to-consumer genomics in the U.S. context imagines the subject as a rational consumer capable of exercising prudent choices for prevention, the experimental context of the Indian company creates value by imagining the subject as a ‘consumable’, an entity lacking sovereignty and serving Western corporate interests. Likewise, as Sunder Rajan ably demonstrates, in the economy of drug production which is itself locally differentiated and interacts with other zones - like the receding textile industry in the case of Mumbai, which left a sizeable population of unemployed youth to become ‘voluntary subjects’ - what acts as a seamless link is the market logic of creating ‘surplus health’ (Sunder Rajan 2011: 202). In fact, adhering to this market logic means that even as the Western subject is imagined as a consumer practicing free choice, “the consumer who exercises “free” choice in the genomic marketplace does not really have the choice whether to be configured as a consumer in the first place” (ibid.: 201-02). It is precisely here that we find the implications of biological citizenship, as a framework for understanding contemporary subject-constitution, enter into a fundamental contradiction with the very condition that makes it possible, namely, the ‘free’ market.

III. Biological and Moral Hazards: A Brief Look at Bioethics

We thus enter into an over-determined domain where mechanisms of turning life itself into technology are met with mechanisms of controlling the unbridled potentials that

genomics and genetic technologies have put into motion. In fact, the consciousness of the potential for intervening in human genetic constitutions was realised by scientists first with the introduction of recombinant DNA technology in the year 1970 when geneticist Paul Berg created the first virus-bacteria ‘chimera’, combining the genes of two different species of organisms and opening the doors of ‘genetic engineering’ (see Mukherjee 2016: 204). Indeed, describing the technique itself, the renowned biologist Peter Medawar had written at the time:

Genetic engineering implies deliberate genetic change brought about by the manipulation of DNA, the vector of hereditary information. ... Is it not a major truth of technology that anything which is in principle possible will be done ...? Land on the moon? Yes, assuredly. Abolish smallpox? A pleasure. Make up for the deficiencies in the human genome? Mmmm, yes, though that’s more difficult and will take longer. We aren’t there yet, but we are certainly moving in the right direction (cited in Mukherjee 2016: 222).

While presenting his findings to students of genetics in the U.S. and Europe, Berg was made to realise that humanity had entered into the era of ‘possible hazards’, making it imperative to contain both the ‘biohazards of genes’ and the ‘moral hazards of genetics’ (see Mukherjee 2016: 226). While the biological hazards raised fears of such genetic chimeras contaminating humans or the environment and leading to human-made pathologies, the moral hazards implicated the anxieties of eugenics and the overlapping possibilities of therapy and cure. What had followed in the early 1970s was a voluntary one-year moratorium, a pause on the use of engineering procedures before scientists could devise a policy for the containment of the hazards. Public confabulations followed, and the organisation of the Asilomar conference in 1975 would be remembered as a ‘unique conference’ by Berg himself for involving not only scientists but members of the public as well as the media in conference proceedings for a “public discussion of science policy” (see Berg 2008; also Mukherjee 2016: 229-31). In fact, resounding the warning that the genetic engineering technique of recombination put one “in an arena of biology of many unknowns”, the Asilomar conference was successful in developing a multi-level scheme of biohazards of genetically altered organisms and the gradations of containment that they require (Mukherjee 2016: 231). However, as Sheila Jasanoff points out, Asilomar narrowly addressed the regulation of experimenting with DNA as it left unanswered questions of “how to classify the entities created by gene splicing, how to

manage the impacts of industrial biotechnology on agriculture and species diversity, and who should set limits on the purposes, ambitions, and scope of genetic interventions” (Jasanoff 2011: 7). It thus had nothing to contribute towards containing the moral hazards, or what Palsson calls the ‘moral landscapes’ of genetics (see Palsson 2007: 124).

It was this gap surrounding the moral hazard of genetics research that the Ethical, Legal and Social Implications/Issues (ELSI) programme of the HGP opened up, thus widening the very space of bioethics, a domain that had since the development of the Nuremberg Code of 1947 been predominantly concerned with voluntary consent in human subjects research (see Palsson 2007: 125). A 2014 review of the ELSI programme assesses the studies that had been funded under the three broad rubrics of genomics, medicine and societal or legal issues. The review noted that the ELSI funded research on societal or legal issues has had the least impact, even as the early investigations into issues of privacy and discrimination had led to prohibition of discrimination in health insurance and employment according to genetic disorders (see McEwan et al. 2014). An even more major limitation of the programme stems from the fact that it is a science ethics programme funded by a public agency like the National Institutes of Health (NIH), and thus may severely lack in addressing deeper epistemic and ethical problems. In fact, even as the programme has supported research by anthropologists like the one by Taussig, Heath and Rapp (2003) cited in this chapter, the possibility of genomic scientists self-consciously addressing the ethical, legal or social issues in their research has become constrained due to the overly data-driven and capital intensive economy of genomics. Palsson, in fact, drives this point home when he points out that the ELSI programme has “departmentalised ‘ethical’ issues pertaining to the new genetics, relieving the practitioners of biotechnology of much of the responsibility of reflecting on what they were doing and the likely wider implications of their work and ideas” (Palsson 2007: 126). Rose similarly maintains that the ‘bureaucratic’ procedures of the apparatus of bioethics (exemplified in national bioethical committees, and institutional review boards) can often shield medical authorities from “the consequences of [their] contested and controversial decisions” (Rose 2007: 31). In such a situation, it is imperative to pose the question of what falls under the ‘bioethical gaze’ and what is left out of it. Expectedly,

Palsson (2007) overall invokes the presence of a market for humanitarianism in which the rapid professionalization of bioethics can be situated, especially after the HGP. Likewise, exploring the contours of this situation further, Rose explicitly posits that the expansion of bioethics in the “political and regulatory apparatuses of advanced liberal societies ... [can be] one answer to a kind of ‘legitimation crisis’ experienced by genetic and other biotechnologies” (Rose 2007: 30). Indeed, the accidental death of a teenage boy as part of a clinical trial for gene therapy (the case, really, of Jesse Gelsinger), the extraction of an African-American woman’s cancerous cells without her knowledge, and without any due compensation, so as to create the world’s first artificial cell line (the case of Henrietta Lacks) are some events in American history symptomatic of this legitimation crisis.⁷

The field of ‘bioethics’, clearly, needs to be analysed critically in the context of modernity, where the ethical gets separated from the rational process of scientific production and often becomes normative in its articulation (see Bishop and Jotterand 2006). Indeed, often framed from a liberal democratic perspective and mostly manifested in consent forms that presuppose ideas of autonomy and individuality, Western bioethics falls short in investigating the embedded or engaged ‘epistemics’ of identity. Nowhere is this lag more visible than in the context of the Haplotype Map Project (HapMap, for short) that followed the HGP. The aim of HapMap was to find common genetic variants for common diseases among populations based in different geographical locales. Based on the hypothesis that common variants are directly correlated to common diseases, the scientific assumption was soon rejected in the duration of the project. Yet the call of HapMap scientists in convincing people to donate their blood samples was effective for the public as it laid emphasis on community engagement, and in doing so introduced a significant shift in the public face of genomics away from the Human Genome Diversity Project (HGDP).⁸

⁷ The Jesse Gelsinger case was briefly alluded to in fn.5 earlier on in this chapter, which also contains the appropriate reference. For the Henrietta Lacks controversy, see Reardon (2017: 8-9). For a further assessment of the current state of moral discourse in bioethics, see Pellegrino (2006).

⁸ The HGDP marked an initiative in the 1990s, which was quite independent of the HGP and the HapMap project. Where the latter (HGP) attempted to sequence one human genome, the imperative of studying human genetic variation and its causation got a renewed emphasis in the HGDP. Indeed, as Jenny Reardon

The latter (that is, HGDP) had propagated a sort of ‘racist science’ as it claimed to map ‘small, isolated’ indigenous communities in order to assess the diversity of human DNA in populations that had not been supposedly ‘contaminated’ by mixed breeding (see Reardon 2017: 71). Indeed, in the face of a backlash from community leaders of indigenous groups and critical biologists, the leaders of HapMap decided to approach larger and dominant communities for their new endeavour. However, being a mega-scientific project like the hitherto HGP, the communities that HapMap engaged with were demanding their participation on the basis of larger collectivities like nationhood, citizenship and humanity (ibid.: 88). More emphatically, the ‘disconnect’ that people faced with informed consent forms which urged them to act as autonomous individuals stemmed from the fact that there was no official recognition of political collectivities giving their consent for collecting blood samples. Thus, in the process of moving away from the racist gaze of HGDP, the HapMap project ended up ignoring the marginal communities within the developed world (the U.S. in particular) and excluding them from an international project that marked new lines of identification and citizenship. Following from these paradoxical circumstances, Reardon accurately suggests that Western bioethics cannot tackle issues of what Jasanoff (2011) has aptly termed ‘bioconstitutionalism’, in particular the question of how to define ‘people’ in any situation according to their self-identification and independent of the categories formulated by the state and its authorities. To be sure, a critical perspective on the ELSI approach as a whole as situated within the larger sphere of bioethics brings to the forefront a key question – one sensitive to the overall enterprise of modern genomics – namely, “how human beings should be defined and cared for in the genomic era, and who

has usefully recounted: “[A]s the sequencing of the human genome neared completion in the late 1990s, leaders of the HGP at the National Human Genome Research Institute (NHGRI) significantly changed their position. While comparing the human genome sequence to the sequences of other species – such as the mouse and the platypus – might reveal some things about human evolution, the possibility of genomic understandings of human disease necessitated understanding how *human* genomes differ. Thus, even before the Human Genome Project came to an official close, the NHGRI initiated an effort to collect samples from different populations from around the world – what would become known as the International Haplotype Map Project (or HapMap ...)” [Reardon 2017: 6]. The HGDP was largely a private, non-governmental initiative, which in its inception in the early 1990s clearly set itself apart from the HGP. Note also the arguments that follow in the text. A fuller history of these initiatives can be had from Reardon (2017: esp. Ch.4).

[has] the expertise and rights to answer these fundamental questions” (Reardon 2017: 92).

Coda: In closing ...

We had begun this chapter cursorily with descriptions of the imaginary of genomic determinism as located in the informational epistemologies of life and a reductive molecular biology of the mid-20th century (as distinct from, albeit not opposed to, the condition of postgenomic complexity that would soon transpire). Without doubt, the terms of this elucidation and contrast was played out in contestations over the control and distribution of genetic information, and the performative and actual competition and cooperation between the public and private sectors in the charged environment of modern genomics. Employing the idea of ‘imaginaries’ as an analytical tool, we observed how complexity implicates both the biological and the social specifically in the times of postgenomics, when the determinist representations of the genome are giving way to other biological ‘omes’ and further theorisations of biological and social life based on complexity, multiplicity and uncertainty. In a foundational sense, the various biotechnological interventions into the genetic presents and futures of human beings (as indeed other creatures and objects) embody these multiple intersections. Needless to say, a vital space opens up before present-day postgenomics between human-made technology and the affects they create within individuals and the community. These ‘regimes of living’, in which people mould their lives according to their genetic test results, are also ways of subjectification, modalities that are by no means homogenous being neither exclusively individualising nor collectivising and yet embodying these forms. Mediating these regimes of biotechnology and societal networks of kin and family are the rules and guidelines of bioethics that by their very formulation occupy a political dimension in the economy of genomics and biomedicine. Bioethical regimes of whatever sort invariably fall short of assessing the specific cultural histories of communities. Indeed, it is in the context of such uncertain encounters where a differential distribution of societal resources and endowments meets with the demands of a high-tech science like genomics that one is confronted with the possibility of creating multiple ethical valuations towards life forms and living itself.

Chapter 5



Recapitulation with Variations: Concluding the Encounter

History of science documents what is known, not what is; intellectual categories rather than things in themselves. ... An ontology that is true to objects that are at once real and historical has yet to come into being, but it is already clear that it will be an ontology in motion (Daston 2000: 13-14).

Across the space of this study, we have tried to map a rather sharp and condensed history in the course of which life - across human forms and other organisms - came to be known, conceptualised, technologized and intervened upon. We also observed how these knowledges, conceptualisations, and technologically-driven interventions, ostensibly rooted in an epistemological quest to know the world and reshape it, have come to express, redefine and even create certain 'regimes of living' for various species, including the human. In fact, by broaching life as a concept, these ways of knowing life have been mediated through the different domains of existence that the human condition embodies. Of course, within the overall contours of this dissertation, we drew our attention towards the primacy of the discursive products of science generally, and those of biology in particular, in governing ideas of life and practices of living. Without doubt, the question of life has been both overtly and covertly a discursive problem for a time spanning much longer than that of modern science, and certainly longer from that of modern biology. Legal texts, the profession of civic virtues and religious literatures are but a few examples of modalities that have made life known to us. And yet there is something distinctive and universalising about the idea of life as biological as given to us by science.

Thinking through such a formulation of life, the religious studies scholar Gil Anijdar (2011), in the wake of Foucault's conceptualisation of the modern subject arising at the intersection of life, labour and language, explicitly states that the meaning of life is not a

given waiting to be discovered, but rather constituted by the multiple agencies of science, law and economics. Asserting life as always already biological life (even as it is not reducible to that), Anijdar points out that at least since the 18th century life gets predominantly established as biological life and that this gets further ‘sedimented’ in law and economics (Anijdar 2011: 699). The primacy of the biological in constituting life is accordingly not granted in any naturalistic sense, but rather produced (ibid.: 705); and, what is more, this primacy of biology “may be less because we have settled on the meaning of life than because we have inherited a certain frame of understanding and knowledge, an episteme, such as Foucault described it for us” (ibid.: 703). In fact, as Anijdar puts in perspective, for Foucault the ‘biologisation of life’ and the ‘politicisation of the biological’ is the very condition of modernity and the novelty of life that the condition frames (ibid.: 710). The two processes implicate both the biological as well as the social in reorienting the concept of life, thereby necessitating the idiom of ‘co-production’ that Jasanoff uses to think about “both present and past human activity” in which the natural and social orders are “produced together” (Jasanoff 2004: 2).

Life in Science and Society: An Internal Recapitulation

It is broadly against this condensed backdrop that our dissertation situates itself. After introducing the theoretical and methodological considerations that guide the overall work in our first chapter, we sought to engage in the second chapter with some determinations of life as part of the historical development of science, indeed both before and after the formalisation of biology. By doing so, the point that we wanted to highlight had essentially to do with how the concept of life has mutated in the history of science, and is thus inextricably bound up with the historical conditions in which science and its epistemological tools of inquiry have come to be fashioned. Through a recourse to historians and philosophers of science who have taken on the task of studying such problem spaces as life, biology, evolution, information, and vitalism, we formulated a condensed narrative about how in the time spanning from the pre-history of science as natural philosophy to the arrival of new sciences and technologies of life since the 20th

century there have proliferated determinate visions of life albeit at different levels of analysis.

To be sure, in the course of Ch.2, we followed the theorisation of life in the sciences specifically in the debates between vitalist and mechanist forms of thinking. To recount briefly: within broadly Western lineages of antiquity, life was studied as part and parcel of the cosmos, and also inseparably from the question of what it means to live a good life in this scheme of things. Following Canguilhem's emphasis on vitalism, we observed how the lineage of concepts such as animate and inanimate bodies came from the "metaphysical identification of life with the soul and of the soul with breath" (Canguilhem 1994: 74). Interestingly, yet, even as Aristotle has been recognised as the forbearer of biological life in the history and philosophy of science (see, broadly, Simondon 2012, as also Canguilhem 1994 and 2008 [1966]), an "anthropological difference" going back to Socrates comes to be established in medieval philosophy with the formalisation of modern science, particularly in the science of mechanics (or physics *per se*). Mechanistic thinking, as we saw in the second chapter, proposes a kind of determinism towards and reduction of life to a physical phenomenon. All the same, strands of both vitalism and mechanism keep appearing in the history of life and the history of biology with regard to the gene, as our Chs.2-3 sought to adumbrate.

Drawing the limits of a non-material vital force, Darwin had articulated the living being as an organism outside of its categorisation within a species or a genus. And yet he had sought to retain the vital character of the being through what Canguilhem (2008 [1966]) has called the 'normative relation' to living (in other words, the vital point that the interaction between an organism and its environment is not pre-given, but produced). The Darwinian theory of evolution had, in a manner of speaking, inaugurated modern biology as the science of life. Even as we cannot deny the veracity of this claim that finds validation from both scientific (like that of Mayr 1997) and social scientific perspectives (see Foucault 2002 [1970]), we went on to trace some conceptualisations of life before the birth of modern biology, finding routes in natural philosophy through the object of soul (in Ch.2) and natural history through the object of species (in Ch.3). All

the same, life comes to be configured in particular ways at the moment of its ‘biologisation’ (to use Anijdar’s term), especially emerging with the sovereign state’s management of population via control of health, disease, sexuality, food, and pharmaceutical drugs. This form of governance of life, theorised by Foucault as ‘biopolitics’ and as taken further and reformulated in the accounts of Rose (2007) and Rabinow (1996), foregrounds the relationship between the vitality of politics and the economic and political significance of biological life.

These historically older knots in which life emerged come into contact with more contemporary moments from the 20th century onwards when the biologisation of life meets a technocratic rationality towards organisms and their health. Arising particularly at the intersection of computer science, cybernetics and laboratory sciences, and being practiced in the domains of new fields of application like synthetic biology and computational linguistics, life as form was being separated from the very matter of which it is made. Indeed, this technocratic turn to approaching life has entailed what Hannah Landecker, in postulating a history of culturing living cells in the laboratory, has designated as the ‘plasticity and temporality’ of living matter (see Landecker 2007: 1). More pointedly, following Landecker, we can say that our present ideas of life are constitutive of approaching and manipulating living matter as technological matter. These goings-on based on the conception of life as an organic unity made up of information containing parts have in turn produced new objects of vitality, those that may not fit into the neat categories of organic and inorganic, and thus rendered the meaning of life even more uncertain today.

On the ‘molecularisation’ of Biology (or, where did the genome come from?)

The third chapter of our dissertation sought to dwell on a history of what Rose (2007) has called the informational epistemology of contemporary life sciences as it comes to be established with regard to the knowledge of heredity and genes (as indeed its successor, the ‘genome’) and how the spaces of this knowledge came to stand in for the fabric of life itself. Within the disciplinary space of biology and its predecessor in the shape of natural history, we tracked a trajectory in the science of life, in the context of which the

movement from species to the genome represents a movement towards the ‘molecularisation’ of life. Here again we found ourselves among historians of science predominantly, trying not to explain the contemporary landscape of genomics as an irreducibly unique formation, but rather finding lineages in the concepts and methods of science and how they travel from one field of research to another. Accordingly, our undertaking through the spaces of Ch.3 involved historicising the ‘agents’ of life, namely, organisms, genes and the genome.

But of course our reconstructions of the trajectory in biology involved three historical movements: from natural history to biology, from 19th century biology to molecular biology, and finally the movement towards modern genomics. Taking off from Foucault’s diagnosis that life arose in the moment of transition from natural history to biology as a founding episteme of modernity, we reconstructed the shift from the classificatory exercises of taxonomy, those that involved creating a grid of similarity in nature before the organic-inorganic divide gets established, to the birth of modern biology in the 19th century which emerged as a science of the individual organism. If the visible surface of observable similarity (as, for instance, the number of petals in a flower or limbs in a body) guided the epistemology of natural history, then biology was necessarily about the invisibility of the similarity that binds organisms together and bringing out their heritable differences to the surface. The formation of the ‘inner milieu’ through Bernard, the ‘anatomic disarticulation’ of Cuvier, Darwin’s descent by modification and Mendelian units of inheritance had all brought the organism into existence as the dominant unit of analysis in biological research.

This deeper “background of an identity” (as Foucault (2002 [1970]: 288) sharply termed it) which constituted the organism comes to be consolidated in our view as the knowledge of genes progressed and developed as part of molecular biology. Following historians, scientists and sociologists of science, we took classical genetics and molecular biology as two separate problem spaces with different objects, techniques and model organisms to work with. Classical genetics, as we saw, took as its object the problem of heredity in terms of the transmission of traits. Relying on the techniques of hybridisation, most

model organisms used were plants, animals such as mice and later the fruit fly (as popularised by Morgan). By contrast, molecular biology, insofar as it pertained to the gene, had made its object to ‘naturalise’ life, that is, to find the exact physico-chemical constitution of the gene molecule, using techniques from a range of disciplines (physics, chemistry, pathology etc.) and model organisms whose molecular level was more accessible to reach, such as bacteria and viruses. This shift was primarily facilitated by improved optical devices such as the electron microscope, all as part of the overall ‘technological landscape’ of molecular biology (see Kay 1993) and each able to penetrate into subatomic parts of life (see Morange 2008).

Deriving different concepts of the gene from these two periods in biology, and following from the work of conceptually-minded historians, we broadly engaged with the notions of the ‘classical gene’ and the ‘molecular gene’ before opening out to the ‘genome’. Indeed, in recounting how these different concepts of the gene were characterised, we highlighted some metaphors - following Keller (2000 and 2008) - that have driven research within the two fields. Thus, as we postulated in the course of Ch.3, even as concrete knowledge of the structure and function of the classical gene was lacking, the concept of ‘gene action’ was a loosely framed, deliberately unclear concept, which in its very formulation assigned vitality to the gene (albeit suggesting only that it possessed the causal agency to act). However, as we further observed, the power of metaphors in science derives from their operational role in driving research, and ‘gene action’ had enabled geneticists to operationalise their research into what could be known, given the constraints in knowledge and techniques available at the time. In contradistinction, the molecular gene that was recognised to be composed of DNA, the information carrying molecule, was articulated in such metaphors as the ‘genetic code’ or ‘the blueprint of life’, with its function being further established in the phraseology of the ‘genetic programme’ and the ‘central dogma of life’. Even as these articulations served different purposes at different moments, all the metaphors for the molecular gene had sought to underscore the informational terms in which the organism was perceived, all being materialised in a molecular vision towards life.

Consolidating this molecular vision, broadly, is the modification of the scientific gaze from genes to the whole genome. However, even before the turn to the genome, molecular biology had drawn the limits of identifying the gene with DNA exclusively, as exemplified in the system of the genetic programme designed by Jacob and Monod which insisted that the expression of genes was part of a larger cellular mechanism and as such relied not only on the DNA molecule, but on RNA as well as proteins creating a feedback circuitry of information. This was the cybernetic vision of life as materialised through the gene, even as the rise of molecular biology (in contrast to popular accounts) preceded that of these post-second world war visions. As such, the scientific acknowledgement of the genome as a dynamic and flexible entity since the early years of the 21st century has necessarily meant undercutting the applications of a reductionist molecular biology.

Further Complications: Gene as ‘Scientific Object’ and other Matters of Concern

It should be emphasised that, by recalling this historical trajectory in biology, we approach the gene as a ‘scientific object’ (see Daston 2000), one further reinforced by the “changing epistemic and experimental dispositions” (Rheinberger 2000: 219) with which the discipline has engaged with the question of life through organisms, genes and the genome. The gene becomes in this analysis the most important ‘boundary object’, gathered together through “conceptual translations between different domains” of biological research and the social worlds in which the biologists participate (see Rheinberger, *ibid.*). In fact, insofar as the genome is the direct and a more recent descendant of the gene, the historical, philosophical and sociological descriptions that we engaged – across Chs.3-4 - were inevitably interested in questions of the birth, growth and (contested) death of the gene.

To reiterate from our introductory chapter, such investigations into the very making of a scientific object direct our attention to the historically variable conditions that make objects of empirical research come into existence, even sustain their presence and in some cases render them obsolete (see Daston 2000; also Feest and Sturm 2011). A constitutive

part of these historically variable conditions is the epistemic and experimental conditions in which science is practiced, which in turn are mediated by what Rheinberger demarcates as ‘boundary concepts’ needed to describe, sustain, and bring into existence “vaguely bounded research objects” such as the gene (Rheinberger 2000: 221). These boundary concepts, like metaphors, gain operational power for their vagueness and exuberance rather than their precision. In fact, Rheinberger goes so far as to say that seeking precision and codifying meaning in such boundary concepts, which are intrinsically supposed to reach out into what is still unknown, can do more epistemological harm than good. (ibid.: 222-23).

A similar view of how to account for objects (scientific or otherwise) comes from the renowned science studies scholar Bruno Latour (2004). In Latour’s revised position of critique, it is not enough to recount the conditions that have made an object (or a fact) possible, to eventually say that the object concerned is socially constructed by laying bare its deconstructed reality. Indeed, in thinking about how humans can more comprehensively relate with objects, Latour conclusively demonstrates that the latter (namely, objects) are neither too weak to be treated as fetishes projected by society nor strong enough to be regarded as causal explanations for unconscious human actions (see Latour 2004). Translating the framework of this elucidation to the critical view of the gene as a ‘boundary object’ (or even simply as a scientific object), our position in this dissertation has been argue against the view of the gene as emerging solely as an artefact of social projects (as, for example, in forced sterilisation and other eugenics campaigns). All the same, our work also tried to sound the limits of the notion that the gene is the single or even the most fundamental natural entity that guides organisms, a position held by a reductionist molecular biology. Latour’s own proposal is that critique should go beyond ‘matters of fact’ and rather approach objects as ‘matters of concern’, a twist further necessitated by the fact that the objects of contemporary science and technology have become a matter of concern outside the world of science as well. In such a charged context, the question precisely of whose concern brings objects into existence becomes an important matter. If today our relationship with life is mediated by its technological interventions and refinements, then who has the power to create technical matter out of

forms of life (or mediate between the technologies of life and the lives of people) as indeed the question who is on the receiving end of those technologies becomes a matter of political and ethical debate and contention.

Genomics in biomedicine: life, technology and people

Following Latour's strategy, accordingly, our attempt in Ch.4 primarily was to open out to the world in which modern genomics has participated. By way of focus and direction, we restricted our examination to aspects of the encounter between modern genomics and biomedicine in the contemporary era. Indeed, our selective attention to the Human Genome Project (HGP), itself mediating between genomic and postgenomic landscapes, was justified in the light of the project's promises to bring genomic technologies to modern health and medicine and benefit the larger social sphere. Here again, the different imaginaries in which the project was both designed and in turn gave rise to could be better grasped through the analytic of the 'co-production' of scientific and sociocultural spheres. In fact, the differential play of genomic and postgenomic imaginaries has consisted not only in a reformulation of biological research through digitisation – in the process rendering uncertain how genomic data can be interpreted and also what it means biologically - but also in the control of biological information in the public sphere, its capitalisation by both statist and market authorities and its storage in digital repositories called 'biobanks'.

More specifically, the 'geneticisation' of biomedicine recorded by anthropologists since the 1970s provided us with a biopolitical landscape within which we approached the question of the subjectification of individuals and populations. The ethnographic instances of the technologies such as genetic testing and screening widely expanding in the advanced liberal world bring into focus the pointed question of individual assessments of future risk, while also entailing the production of subjectivities that are both individualising and collectivising. The concept of 'biological citizenship' as put forth by Rose and Novas (2005), and that of 'biosociality' as urged even earlier by Rabinow (1996), are some ways in which anthropologists and sociologists have engaged with the grounds of this biopolitical landscape, all involving new forms of activism

around certain diseases outside of biomedical institutions. At any rate, the activities of various agencies of global ‘biocapital’ (see Sunder Rajan 2011), while postulating new ‘experimental subjects’ and biomedicalising genomic research on traditionally dispossessed communities, have brought out fissures in the positive consequences of this new biopolitics and the limitations of the bioethical regimes in the present. These fissures highlight the fact that even though the technological apparatuses of modern genomics and biomedical research actively call for participation from the public at large, the ‘people’ who are able to assimilate their hopes within these apparatuses are precisely those who possess some educational and economic resources.

Indeed, these capital and data-driven big science projects have rendered true Rabinow’s prediction that in the near future “post-disciplinary practices will coexist with disciplinary technologies” (Rabinow 1996: 103) while further entrenching racial, ethnic, class and economic differences. Bioethical regimes, largely institutionalised following from the excesses of the Nazi regime, have themselves been assimilated to a great extent into the market regimes of science, technology and health. Their increased and exclusive focus on liberal ideals such as individual consent imply a reliance on ideas of autonomy that may not even apply to the whole of advanced liberal world, let alone other societies in the global polity. In fact, today more than ever, when genomics has given rise to technologies of editing life itself, deliberately changing not only the course of an illness but also the individual’s overall life-course, bioethical formalities present the opportunity of ‘black-boxing’ matters of biological and moral hazards stemming from the actions of the scientists and doctors in various institutional precincts.

A Note on Limitations and Some Further Questions

It should be pretty obvious that the very grounds traversed by our study also entail its limitations, augmented further by the fact that we were mindful about not opening out to multiple threads of analysis. In a nutshell, our endeavour has been to paint an internal picture of life in the contemporary through the processes activated by the turn to modern genomics. While doing so, we also took into account the older systems of knowledge

and life that the contemporary builds on, as indeed the newness that this uncertain encounter entails both for our present and future. Undeniably, in the course of articulating both the knowledge systems of science and the forms of living in the present, we are constrained by Western lineages of thought and practices. These lineages can make for common forms of knowledge and living, but can involve very different assumptions and trajectories when located explicitly in a non-Western setting. It will be profoundly interesting, for instance, to pursue the question of how life has been conceptualised in Indian thought and to redraw its connections with distinctive regimes of health and medicine in India, even as must acknowledge that the global biotechnologies have created many homogenising effects across national contexts.

Now, of course, across the space of our dissertation pursuing in particular the epistemic conditions of problematizations of life and the gene, we have steered clear from conceptualising long-term epistemological change, which is another key aspect of any analysis of scientific practices and objects. We have used phrases like ‘genomics revolution’ and ‘postgenomics’, but clearly we need fuller accounts of what characterises these transitions over time, and accordingly deepening the context in which science is practiced and analysed across durations of time. In the same spirit, we may need to locate in time a definitive historical shift from a politics that revolved around ‘bare life’ to one centred on a form of life (see, among others, Campbell [2011]), while also examining the bearing of this shift for the worlds of science. Needless to say, such engaged chronological frames of analysis would require a more sustained attention to philosophy and history as well as to the anthropology of science and politics. The dialogue between science, technology and society is bound to be a protracted one.



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