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Chapter Nine

Science: The Structure of Scientific Evolutions

David Dunér

Scientific thinking is a result of time and history. It has slowly emerged in bio-cultural coevolution where human beings interact with artefacts and the surrounding environment. Fundamental conditions for the emergence of scientific thinking are that the human mind is embodied, environmentally situated and using external objects to extend its senses and cognition. But also important is the prerequisite and urge to communicate and have encounters with other thinking and living beings. Taken together, this amounts to the human ability to understand and share knowledge, beliefs and perspectives, and to do so in a context beyond that of the intimate group. This chapter discusses how science emerged through interaction between human cognitive abilities and changing environmental conditions, in other words, how it depends on an extensive bio-cultural coevolution. “Science” is here understood in a broad sense, as the systematic organisation of knowledge by human beings with the aim of understanding, explaining, and handling the world around us, as applied to nature as well as to culture and society. It is a disciplined way of studying the human Lifeworld, by using certain cognitive and cultural abilities that have evolved through a bio-cultural coevolution. Even if scientific thought, as we shall see, resembles human thinking in general, it tries to transcend the subjectively and culturally coloured Lifeworld, aiming to an intersubjective, shared Lifeworld, grounded in universal features of human consciousness.

9.1. The Prehistory of Science

We have good reasons to assume that at the end of the Pleistocene, 11.7 ka ago, the cognitive abilities needed for scientific thinking were at hand (Mithen 1996, 2002; cf. Donald 1991, 2001; Renfrew, Frith & Malafouris 2009). Modern hominines of the subspecies *Homo sapiens sapiens*, living in the Palaeolithic age, were able to make detailed observations of the natural world around them, they were able to generalise and draw conclusions to make predictions and test hypotheses. They could deal with complex social relationships and the demands of a changing environment. They had

technology, such as stone flakes and choppers that required an ability to plan, to coordinate hand and eye, and to imagine a preconceived form. One of the most crucial cognitive capacities for science was also in place – probably as a result of increased sociability, tool-using and coordination of hunting – i.e. the ability to form ideas about other minds, other people's thoughts and desires, to understand their actions, to see causal connections between an action and the effect it may have on others. The ability to imagine other people's inner worlds was an important precondition for the emergence of language and other communicative abilities. Apart from making use of analogies and metaphors to develop abstract ideas and reasoning, early human beings could reinforce their thinking by utilising objects as artificial memory devices to store and transfer knowledge. At around 50 ka, according to Steven Mithen (2002), the first traces of accumulated knowledge seem to appear.

But there was still something crucial missing. At the end of the last ice age human beings became resident, grew crops and kept livestock, which allowed for providing the necessities of life to an increasing number of people. The communities became larger, which gave rise to more frequent social contacts, increased trade, and faster exchange of ideas and thoughts that were shared and distributed. When the products for living were sufficient for more people than those who produced it, some people could put aside the production of the life-sustaining necessities, and became instead able to engage in specialised tasks. The knowledge of plant and animal reproduction increased, as well as that with reference to building construction, chemical processing and handicraft. In fact, social, cultural, and economic factors led to a cognitive change. The earliest civilisations, the Indus culture, Egypt, and Mesopotamia at the time around 10 ka, were not results of an emergence of a new cognitive ability, but of a new way of using earlier cognitive abilities in a changed social and cultural environment. Probably the new way of organising human life and living, epitomised in the communal forms for living that led to city-like environments, had a great impact on human thinking (see further Chapter 8: Urbanity in this volume). The first writing systems, which emerge around the same time, gave rise to an increased capacity to store and transfer knowledge. Thus, at this time, a range of fundamental prerequisites for human rational and complex scientific thinking was in place. But still we have to wait until the sixth century BCE for the dawn of natural philosophy of the ancient Greek Pre-Socratic

philosophers, and two centuries later for the systematic, teleological programme of Aristotelian physics, and additionally two millennia until the sixteenth and seventeenth century CE before the rise of modern systematic natural science. This needs an explanation.

Human biology and the genetically conditioned evolution of cognition are necessary prerequisites, but in themselves are not sufficient explanations for the emergence of scientific thinking. Nor is it satisfactory to explain scientific change and succession of theories by mere applying – in a sort of reductionist analogy argument – the theory of natural selection with interactors, replicators, or memes (Toulmin 1972; Dawkins 1976; Hull 1988; Wuketits 1990; Rosenberg 1992; Vicente 2000). Instead, we have to search for cultural-evolutionary explanations behind the rise of the scientific endeavour. Culture could be defined as the existence of differences between groups within a species in terms of behavioural patterns, which are not directly determined by ecological factors, but taught and passed on to new generations (Sinha 2009). Culture, in this sense, is a kind of stock of inherited memories. In the course of human development cultural changes occurred, which in turn had an impact on our cognitive abilities, that is, a cultural evolution appears in interaction with the specific environmental and biological resources. For a complete picture of the development of human thinking, we must avail ourselves of not only phylogenetic and ontogenetic explanations, but also of cultural-historical explanations. Modern adult human cognition is a result of not only genetic events that have occurred over millions of years of evolutionary time, but also cultural events that have taken place over many thousands of years of recorded history and personal events during thousands of hours in ontogenetic time (Tomasello 1999, 2005). The cultural process gave rise to unique human material and symbolic artefacts, which, in their turn, created a cultural niche that has had an impact on human cognition (Tooby & Cosmides 1995; Damerow 1996; Strauss & Quinn 1997; Cronk 1999; Simpson, Stich, Carruthers & Laurence 2006). Scientific thinking and human systematic search for knowledge are in other words completely anchored within the theoretic stage, i.e. the level of cognitive-semiotic skills that, according to Donald (1991, 2001), encompass both verbal and nonverbal extensive external symbolisation, a large amount of theoretic artefacts and massive external memory storage, as well as institutionalised paradigmatic thought and invention.

Cultural-evolutionary studies of human history therefore have an important role to play in establishing the connection between early hominines and contemporary human beings in order to achieve an understanding of the emergence of human thought and culture. Science, which is obviously a cultural artefact or activity, is a result of a bio-cultural coevolution: it requires fundamental cognitive skills (that were already, more or less, in place at least 130 ka ago), but – what is more important – it is a result of the interplay between the human cognitive skills and the changing socio-cultural and physical environment. In line with phenomenology (Husserl 1900–1901; Merleau-Ponty 1945; Gallagher & Zahavi 2008) as well as enactive cognitive science (Varela, Thompson & Rosch 1991; Thompson 2007), the “scientist” is, as a human being, an embodied, moving, and interactive subject. Scientific thinking arises in a dynamic interplay between acting human beings and their environment, between the thinking, interactive mind, and the experiential world. Our knowledge of the world, as Shaun Gallagher and Dan Zahavi (2008, p. 89) claim, “including our scientific knowledge, arises from a first-person perspective, and that science would be meaningless without the experiential world” (see Zlatev 2009). What is put forward here is an interaction theory of the emergence of science, an enactive theory of scientific evolution.

9.2. The Scientific (R)Evolution

The long history of the interaction of the human mind with its environment has given rise to different cognitive tools for interpreting and dealing with the world. The question here is how these cognitive resources – that are also found in other human and everyday thought operations – are used in scientific thought, particularly in seventeenth and eighteenth-century science, during the so-called “scientific revolution.” The main idea is simply that the problem-solving strategies in science and technology are not radically different from other human activities, but can be seen as sophisticated, refined versions of everyday thought processes in interaction with a specific spatial and temporal environment. Deduction and induction have traditionally been identified as the most important and distinctive tools of that activity we call science (cf. Losee 2001). But these are just examples of a larger set of cognitive tools that are applied in scientific reasoning. Thus, science cannot be distinguished from other human activities by referring to a particular cognitive process that is exclusive to science. Instead, “science”

can be seen as a category, formed by a specific culture in a specific time, in which certain sciences serve as prototypes, as more typical sciences, such as physics, chemistry and biology, and other less typical or different in kind such as art history, literature, and theology. The various scientific disciplines share many characteristics with each other, have common family resemblances in Ludwig Wittgenstein's (1953) sense, but lack a common essential feature necessary in order to be called a science (cf. Dunbar 2002). Instead of searching for the one and only unity of science, we should look for the plurality of scientific practices. Science is not distinguished from other human enterprises cognitively, but by the specific objectives of its activities, i.e. to increase our knowledge in a systematic way about the world and ourselves, seeking true statements and put forward propositions that are verifiable, or, according to Karl Popper (1963), at least falsifiable. What should be regarded as science or not, is also to a large extent a matter of debate within the scientific community, as a consequence of an agreement about the nature of "normal science," the paradigm or episteme, as this has been put forward among historians of science ever since Thomas Kuhn (1962) and Michel Foucault (1966).

Philosophers, scientists, theologians, and political thinkers use basically the same cognitive abilities that ordinary people do in their own culture (Nersessian 1992, 1995, 2005; Lawson 1994, 2004; Gooding 2000; Giere 1988, 1992; Gentner & Jeziorski 1989). Scientists incorporate concepts that are available in their contemporary historical context and the general theories, models and metaphors that are common and typical of the culture in which they are included, but they also remodel and differentiate these basic concepts, discover new connections and draw new conclusions. Science aims, like literature, art and myths, to manage life, to find order in the world. Human thoughts and feelings are indispensable tools to find meaning in what is going on around us. The scientific concepts do not simply represent immediate things but are expressions of human conceptions of things. Science is largely – like religion, politics and art – about human orientation in the world, and the organisation of human experiences of the Lifeworld.

The scientific revolution, which is usually associated with the new explanatory models of the universe and the human body that appeared in the sixteenth and seventeenth century, was in fact a result of how people managed to make use of, in new

ways, all those cognitive skills that have gradually emerged over the past five million years. No fundamental change in the human brain has occurred during the last tens of thousands of years. An explanation of the development of science must, of course, be sought elsewhere. Neither could the explanation be found in the mind alone. The scientific revolution, a concept that can be traced back to the eighteenth century (Cohen 1976), has commonly been described as a period in which new ways of thinking about the world were introduced, either due to theoretical factors, such as mathematics and Platonic philosophy, or with an emphasis on new experimental methods, the introduction of new instruments or a new social organisation of science (Burt 1925; Butterfield 1949; Dijksterhuis 1950; Koyré 1957; Kuhn 1962; Shapin & Schaffer 1985; Shapin 1996; Gaukroger 2006; Harrison 2007). The debate has focused on internal versus external explanations, scientific and theoretical factors versus social and practical-experimental factors. A cognitive perspective defended here may instead provide a unified explanation of what occurred. Internal or external, scientific or social factors, references to a new philosophy or new methods, and so on are each inadequate to explain the emergence of science. We need a way of avoiding positivist and idealist approaches that exclude the context and favour the vision of the mind as playing with ideas, or poststructuralist approaches seeing science as just texts or social constructivist approaches reducing it to mere social interactions or constructions of power among social beings. What is missing is an integrated cognitive theory that counts with both internal and external, scientific and social factors, both mind and matter in interplay. An explanation for the scientific change that appeared during some centuries of the early modern era can instead be found in human cognitive abilities in *interaction* with a changing environment, that is, an enactive theory of scientific evolution.

The phenomenon that we call “the scientific revolution” took place over several centuries, from Nicolaus Copernicus’s *De revolutionibus orbium coelestium* (1543) to Isaac Newton’s *Philosophiae naturalis principia mathematica* (1687), and may extend to Charles Darwin’s *On the Origin of Species* (1859) and the institutionalisation of science in the nineteenth century. From an evolutionary perspective, we learn that completely new phenomena rarely arrive in one blow. The eye did not convert light into mental images after a mutation, a single change of one base pair in the molecules of life. Neither did thinking and consciousness appear from nowhere, but evolved through

a process that took many millions of years. Even science itself rests on an extended evolutionary history. What is called a “revolution” is in most cases the result of a long series of small steps, the accumulated experiences gathered by many generations of thousands of people. In the next section, I will pinpoint some crucial cognitive abilities or “tools” that are inevitable in the structure of scientific evolution.

9.3. Science and Cognition

The scientific change in the sixteenth century and onwards can be explained by the new opportunities for, and ways of, using the given cognitive abilities, which occurred during a relatively limited period of time. Among the cognitive factors underlying this change in scientific activity are:

- External tools to enhance thinking (distributed cognition and extended mind)
- The discovery of new worlds (situated cognition)
- Enhanced senses (perception)
- Stronger links between cause and effect (causality)
- New ways of seeing something as something else (metaphors)
- A renewed interest in systematisation and classification (categorisation)
- New opportunities for collaboration of minds (intersubjectivity)

The change is made up of a multitude of different, mutually intertwined, problem-solving strategies developed during a long period, through several generations of scholars (Nersessian 2002). Instead of mainly looking at the choices scientists and philosophers made between this or that theory, we could study how they, by using their cognitive resources, built up explanatory models. There were various cognitive abilities in action during the scientific revolution, in the on-going interaction between mind and environment. In the following, I will enter more deeply into the seven cognitive abilities (as mentioned above), among a larger set of cognitive resources, that changed science. After a brief explanation of the cognitive abilities involved, I will give concrete examples of how those were utilised in early modern science.

9.3.1. Distributed Cognition and Extended Mind: External Tools to Enhance

Thinking

A number of tools that reinforced the human mind were invented during the early modern period. The most obvious example of an external tool for enhancing thinking introduced at the time is the printing press by which ideas and memories could be stored and distributed to a larger number of recipients. Another external tool, that had a great impact on future science, was the formal, algebraic mathematics by which mathematical calculations could be performed and stored outside the brain, and communicated to, and controlled by, other subjects. In other words, an important reason for the development of science was new forms of distributed cognition that extended the mind, from the brain to the surrounding environment.

According to the theory of distributed cognition (Giere & Moffatt 2003), thinking is not only something that goes on in the brain and the body. Neither is the world around consciousness being just a passive framework, as treated within positivist and idealistic approaches to science. Thoughts and memories are also placed and stored in the world, in things outside the head, in images, texts, and objects, and they are manipulated with pencils, books, calendars, maps and machines as external memory banks and thought processors. We use various tools and the environment around us to strengthen our thinking. Thoughts are stored in things, can be manipulated and changed outside the brain, and as external memories, they can be shared with other people. In other words, material culture is an extension of our bodies and our thinking, and thus also becomes an indispensable element in our understanding of the thoughts and ideas of a historical time. The written sources, documents, notes, books, and pictures, which are the most important sources in historical research for accessing the thoughts of the past, can be understood as samples of distributed cognition.

We think with books and pens. Reading gives us associations and clues, force us to come up with interpretations, and give us suggestions and material for further thinking. When we are writing, we have to concretise our thoughts, we try to find the right words for our mental images. Communication in that sense may be said to be an attempt to transfer mental images, via a medium, from one consciousness to another. A key to the thinking of people in history, how they came up with their ideas, is how they communicated, read and wrote, how they interpreted texts, tried to find a meaning in them that they could use for their own thinking (Ong 1982; Lotman 1990; Bruner 1991;

Chartier 1992; Tsur 1992; Carroll 1995; Turner 1996; Portis-Winner 1999; Crane 2000; Fauconnier & Turner 2002; Herman 2002; Jackson 2002; Stockwell 2002; Gavins & Steen 2003; Boyd 2009; Brône & Vandaele 2009). Reading includes interpretation, perception, and previous knowledge. The reader engages his cognitive abilities in order to decode the text, he or she gets certain associations, establishes personal relationships, gets personal mental images, interprets texts according to the aesthetic, religious, or scientific norms of his or her time. The books in the libraries were not the actual sources of a certain person's ideas, but rather, the books can be regarded as tools for his or her thinking, as a part of the distributed cognition. Ideas come not directly from books and authorities, but from the human mind in *interaction* with things and objects. Thus, by taking into account distributed cognition, how people used things and objects in their thinking, such as images, books, tools and technologies, i.e. how they stored memories in material culture, and how they read, interpreted, and manipulated texts, one could approach a deeper understanding of human thinking in history.

The printing press with movable types, which was introduced in Europe by Johann Gutenberg around 1450, led to a strengthening of memory, and facilitated and increased the dissemination of ideas. Memories could be stored in external memory holders, such as printed books, and the internal memory of the human brain could be unburdened. An increasing number of encyclopaedias and dictionaries flowed onto the market. The new mathematics, such as analytical geometry and infinitesimal calculus, which was introduced during the seventeenth century, resulted in a strengthening of human deductive reasoning. One can consider the art of printing and mathematics as part of distributed cognition, tools that enhance the human cognitive capacity, that enable humans to outsource and process information outside the cerebral tissues, as exograms (cf. Donald 1991, 2001), and store memories in more stable storage devices, such as printed books. Both printed books and formal mathematics were communicative tools for spreading and transferring information and ideas. With pen and paper, with mathematical calculations, rational thinking could be mechanically performed in a more powerful way outside the brain. The calculations were external representations that also could be manipulated, which in itself basically did not have to use the brain's thought processes and memory. Added to this was also the rationalist philosophy of René Descartes and Gottfried Wilhelm von Leibniz and others that partly put forward a new

way of thinking about thinking, a stronger emphasis on the rational mind as an axiomatic-deductive device. With mathematics as a model, rational thinking was envisioned as a sort of calculation with symbols. To think is to count. Logical thinking was basically a mechanical activity, which opened for the possibility to construct the ultimate mind machine that could produce all truths.

In both mathematics and thought, counting was considered as a mechanical activity, a game played with signs. Correct thinking follows set rules. The mind is a machine, ideas are its raw materials, and conclusions are its products. Step by step, the thinking machine assembles its thoughts into a finished product, and if everything has worked as it should, it then spits out a well-fashioned, incontrovertible truth. The knowledge machine had been a dream ever since the concentric circles of the Catalan Franciscan friar Ramón Llull over four hundred years previously, and in the seventeenth century it was developed into the mechanical calculators of Pascal and Leibniz, who tried in their way to emulate the human calculator. Leibniz even described a logical calculus, a formal inference machine, *calculus ratiocinator*, with which one could figure out all logical truths.

Leibniz, who invented the infinitesimal calculus (in a priority contest with Newton), developed Llull's idea of a "mind machine" in an early work from 1666, *Dissertatio de arte combinatoria* (Yates 1966; Eco 1997 [1993]). Leibniz imagined a "characteristica universalis," consisting of mathematical symbols not unlike Egyptian hieroglyphs and Chinese characters, which at the same time would be a new language, a new logic, method, mnemonic, combinatorics, Kabbalah, and encyclopedia. It would contain all knowledge, and even all future knowledge. No more controversy, no more insoluble problems. People just needed to sit down and say to themselves: "Let us calculate!" The universal mathematics would express relationships between ideas, like in algebra and arithmetic. In April 1679, Leibniz wrote to Johann Friedrich, Duke of Hannover, concerning Llull's *Ars magna*:

For my invention uses reason in its entirety and is, in addition, a judge of controversies, an interpreter of notions, a balance of probabilities, a compass which will guide us over the ocean of experiences, an inventory of things, a table of thoughts, a microscope for scrutinizing present things, a telescope for predicting distant things, a general calculus, an innocent magic, a non-chimerical cabal, a script which all will read in their own language; and even a language which one will be able to learn in a few

weeks, and which will soon be accepted amidst the world. And which will lead the way for the true religion everywhere it goes (Leibniz 1927, p. 168; Eco 1997, p. xii).

Euclidean geometry was a scientific ideal in the seventeenth and eighteenth century. According to the geometric manner, *more geometrico*, the axiomatic-deductive approach in geometry should be the model for all science. In mechanistic natural philosophy, rational thinking was seen as a mechanical activity going step by step in the same way as in geometry, where one starts from some assumed axioms and then arrives at irrefutable, true theorems. The truths of geometry were objective, universal, infallible, absolutely sure, and transcendent, independent of human beings and their minds and bodies. Geometry was not only a decisive characteristic of rational thinking, it also existed in the physical structure of the universe – it was the language of nature. The search for the underlying mathematics of the universe is perhaps one of the most prominent achievements of seventeenth-century science, from Kepler and Galileo to Newton. Mathematics has been hailed since the Antiquity for being precise, consistently stable in different times and societies, understandable across cultures, efficient as a tool for description, explanation, and prediction. The objectivist stance means that concepts and thinking are transcendental and independent of the bodies of the thinking beings, that thinking is a mechanical manipulation of abstract symbols that are meaningless in themselves but are given meaning through correspondence with the things in the world. Mathematical concepts seem to be the same from all reference points, at all times and in all situations. Geometry, as Edmund Husserl (1939) formulated it, is an “ideal objectivity,” and its origin needs an explanation from practice in the Lifeworld. George Lakoff and Rafael Núñez (2000) had questioned the objectivist stance from a cognitive perspective and put forward that mathematics can rather be seen as embodied, as attached to the body, which may also explain the emergence of human mathematics.

The mathematician and probability theorist Blaise Pascal (1658) sums up the geometrical spirit of Cartesian natural philosophy in the words: “What is beyond geometry is beyond us” (Cassirer 1970, p. 143). In *De l’esprit géométrique* (c. 1658), he explains that, thanks to natural light, geometrical science can penetrate nature and its wonderful properties. The true method consists “in defining every term, and in proving every proposition” (Pascal 1909–1914 [1658], p. 429). In the geometric ideal, which is

found in Pascal, there is a quest for the simple, general, and everyday things, beyond esoteric and grandiose, puffed-up mannerism. At the same time, the geometrical method is extremely presumptuous, with a self-assured belief in its ability to arrive at the unreachable, at what is concealed by nature and reason. The axiomatic-deductive tradition was taken to its extreme in Baruch Spinoza's *Ethica ordine geometrico demonstrata* (1677), ethics demonstrated by geometrical method, where he proceeds from God, definitions, axioms, and conclusions in an attempt to build up a system of ethics modelled on indisputable, eternal geometry. A good example of the incremental progress of the geometric method is Spinoza's (2002 [1677], pp. 217–222) evidence for the existence of God. Begin with axiom 7:

If a thing can be conceived as not existing, its essence does not involve existence.

Add to that proposition 7:

Existence belongs to the nature of substance.

Which allows Spinoza to prove God's existence with logic's binding power of persuasion:

Proposition 11: *God, or substance consisting of infinite attributes, each of which expresses eternal and infinite essence, necessarily exists.*

Proof: If you deny this, conceive, if you can, that God does not exist. Therefore (Ax. 7) his essence does not involve existence. But this is absurd (Pr. 7). Therefore God necessarily exists.

With the printing press, the improved ways of storing and communicating knowledge, experiences and ideas, and formal, algebraic mathematics, giving opportunities to calculate outside the brain, in a mechanical infallible way, the human mind got new powerful tools for doing science. The grand narrative of human intellectual history is that of the increasing complexity of distributed cognition, our increasing dependence on other brains (cf. Hutchins 1995) and external tools for thinking and memory (cf. Donald 2008). The Palaeolithic hunter could, in principle, make all his own hunting gear, and his knowledge was dependent on a rather limited

group of people. Gradually, people became increasingly more dependent on the knowledge of a larger number of human beings, from the local community, through the nation, to the inevitable international cooperation of the contemporary global world. Today, no single person can produce or understand, for example, the technology behind a computer on their own, let alone society itself, but we are dependent on other people's knowledge, experiences, and actions. This knowledge has been distributed to a large number of individuals and there is not much we can do and think on our own.

9.3.2. Situated Cognition: The Discovery of New Worlds

The period from the sixteenth to the eighteenth century was an era of great geographical discoveries. New opportunities opened up for travels to other parts of the world, foreign landscapes, and cultures. Human physical space and spatial experience widened. The white spots of Earth were slowly filled with lakes, mountains, towns, and villages. Increased world trade and more frequent international contacts led to new opportunities for scientific expeditions and explorations of unknown geography, which in its turn led to new observations, new knowledge about the world, and a new spatial understanding (see Chapter 10: Encounters in this volume). These travels and widening experiences of the space around the human being changed the situated cognition of the human mind. Encounters of other cultures and the multicultural impacts and exchanges of ideas are certainly major clues to the scientific change during the age of discoveries (cf. Bala 2006).

Travels awake certain thoughts in the travellers' minds; memories and experiences are tied to the physical environment. Human thinking is, according to the theory of situated cognition, situated in the world in a very concrete way, it is not detached from the environment. Our cognitive processes occur not only in our minds, in our bodies, but also the world around the human being is a part of "thinking," and has an active role in the cognitive processes (Clark 1997; Clark & Chalmers 1998; Brinck 2007).

Thinking occurs in the interaction between brain, body, and world. In other words, there is a dynamic interplay between the mind and the environment, which creates a cognitive system consisting of both the subject and the environment. The experience of the space around us is important for our thinking, by the sheer fact that the body is related to and conditioned by the environment through which it moves, the air that is inhaled, the

sounds that vibrate in the auditory canals, what it touches, tastes, smells, and looks at. Perception, bodily movement, and manipulation of objects are indispensable for thinking and for the creation of concepts (Lakoff & Johnson 1999). The experience of the world is a source from which consciousness can draw nourishment. Thinking simply needs the surrounding world in order to function. Day and night, light and darkness, gravitation, landscapes, and winds are part of human thinking.

The new long journeys to unknown parts of the world led to new observations and greater knowledge about the world beyond the well-known and familiar cultures and landscapes. The travels of the naturalist Pehr Löfling and other disciples of Carl Linnaeus became an extension of their master's powers of observation where new specimens were added to an increasingly elaborate system of the diversity of creation. One can especially notice what happened to the human mind in the encounter with the unknown (Dunér 2011, 2013a); how the travellers tried to interpret and understand the unfamiliar environment they came to (see further Chapter 10: Encounters in this volume). These travels led to a new spatial awareness. The travellers had to interpret what the senses conveyed, not uncommonly by using past experiences projected onto the unknown. The encounters with foreign nations changed the travellers, and communication difficulties arose not only in regard to the strangers they met, but also when they tried to describe and communicate what they had seen to their countrymen.

9.3.3. Perception: Enhanced Sensory Abilities

New inventions and tools extended the reach of human senses. Besides the telescope and the microscope, the perhaps most celebrated examples of expanded senses in the beginning of seventeenth century, one can also mention new ways of making and distributing pictures, and a new understanding of what human perception is. Central for the scientific enterprise became systematic observations and experimentations. In the new empirical science emerging in the sixteenth and seventeenth century human senses played a significant role.

We receive, record, and collect information from the surrounding environment by means of our senses, sight, hearing, touch, smell, and taste. But that which the senses convey must be interpreted by specific cognitive processes before it becomes a “reality.” The “reality,” as we experience it, is in some sense created by ourselves, by

our own cognitive processes. We do not just passively receive images and sounds from the surrounding world, rather, the mind seeks patterns in what it receives from the senses through a process determined by both biological and cultural factors. Perception is not a neutral, objective, faithful recording of reality. Our previous knowledge and our concepts affect what we see and do not see. Lacking concepts for a specific phenomenon may lead to difficulties in distinguishing it among other impressions. The world distorts our concepts, but our concepts also distort the world. The interpretation of what we perceive rests on cognitive abilities such as memory and categorisation. Our previous knowledge, which is contained and mediated in our culture, by such means as stories, myths and religious beliefs, but also by scientific explanations, creates meaning in what we encounter. This fact, that our previous knowledge and concepts change our perception and interpretation of what we perceive, is particularly important for historical studies of cultural encounters, travels, and experiences of landscapes and environments, but also for studies of scientific observation. For example, in the optical observations of Venus, especially during the transits in 1761 and 1769 when the planet passed across the solar disk, we find instances of how preconceived understanding shaped the interpretation of what the observers had seen (Dunér 2013e). Through their senses, they received impressions from outer space, and they collected and collated information on distant worlds using their sight. Striking examples of this epistemic perception are the maps of Venus that delineated the surface of the planet, where it was sometimes interpreted as possessing mountains and other geological features. Even a dim light, faint spots and lines, and a companion moon seemed to appear when Venus was viewed through a telescope. The astronomers interpreted their obscure observations in line with their prior knowledge, their experiences, and their ideas of the nature of the world – and they often found what they sought.

The most well-known examples of new devices that expanded human sensory ability are the telescope and the microscope. They enabled the astronomers to look far out into the universe to distant planets and celestial bodies, and let the naturalists look into a microcosmic world of a previously unimagined diversity of life. In 1609 Galileo Galilei trained his telescope on the Moon (see Figure 9.1). In the *Sidereus nuncius* from 1610, he showed, based on his telescopic observations and analogical reasoning, that the Moon had mountains and therefore had the same solid, opaque, and rugged nature as

the Earth (Spranzi 2004), and he discovered never before seen moons of Jupiter, the faces of Venus, and the dark spots of the Sun. The microscope opened up a new unseen world within the human body. Suddenly medical doctors could study the finest vessels and fibres of the body. For example the Italian anatomist Marcello Malpighi found the capillaries connecting veins to arteries through his strengthened, “armed” eyes. Other technical aids, which were part of the enhanced distributed cognition, where various mechanical instruments, such as Christiaan Huygens’ pendulum clock from 1656 and other mechanical clockworks that could describe the time, seconds, the solar year, and the movements of heavenly bodies. The new optical instruments reinforced vision as something fundamental in the description of reality. The world had a visible geometric structure. The scientists and philosophers had to look around themselves, perceive the world, not just listen to ancient authorities. Philosophy should not have an audience, but *spectators*, said the German professor of mathematics and physics Johann Christoph Sturm (Ornstein 1975).

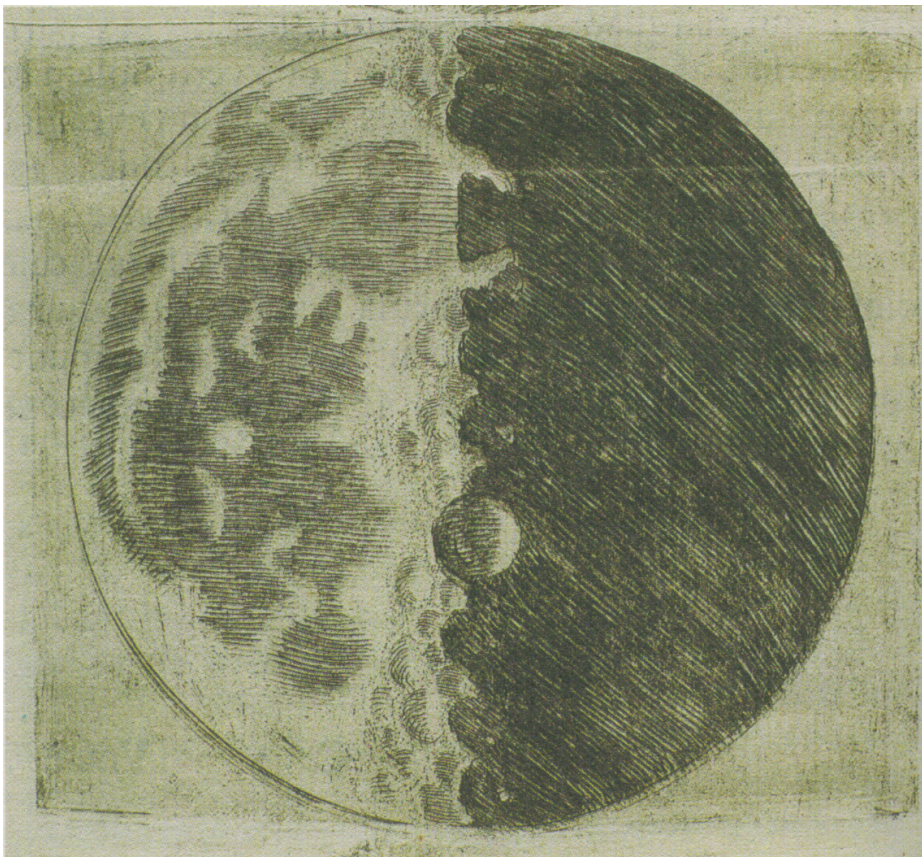


Figure 9.1. In November 30, 1609, Galileo pointed his telescope at the moon and found

a world of mountains, valleys, and plains. The first pictures of the moon as seen through a telescope were published in his book “Sidereal messenger,” *Sidereus nuncius* (1610).

The strengthened perception gave new empirical material for thought. Enhanced senses, in other words, had a special significance for the emerging empirical sciences (Giere 2002). But, apart from the strengthened sensory tools, also new ways of depicting the visual impressions, making and distributing images, may have had an important impact on the emergence of modern science. The linear perspective and the art of printing, and the increased number of images, led to a stronger visual culture that altered the way of viewing the world, a geometric vision that emphasised the objective, abstract, non-verbal features. The one-eyed perspective with a focal point on the horizon line, which had been developed in the Italian Renaissance, according to the geometrical method of perspective demonstrated in 1413 by Filippo Brunelleschi, deviated from the subjective experience and the two-eyed, moving and spherical vision. Seeing was forced into straight lines and into a geometrical Euclidean space. With ruler and compasses one could draw pictures of the world as it is in accordance with geometry. It resulted in a mathematical rationalisation and abstraction of the psycho-physiological spatial perception, which led to the perception of a clear and consistent image of space. From the Renaissance and onwards, there was a new way of seeing, a highly visual culture, where non-verbal thinking was strengthened. The art of perspective detracted vision from subjective to objective experience, to a geometric experience of the world independently of who had the experience; it vanquished and structured a chaotic experience of space. We also find a change from reading aloud and storytelling to quietly reading a book in private (Ong 1982), a change from orality to literacy that in the same time became a movement from auditory to visual stimuli.

Apart from its use in art, as we can discern it in the art of the Italian Renaissance, the perspective became soon useful also in science, and gave new excellent opportunities for medical illustration. With the art of perspective it became possible to make objective and realistic renderings of the human body. During the period, exquisite, lavish and accurate drawings, engravings and woodcuts were produced of the human body and its internal organs, from Vesalius to Willis, Bidloo, Vieussens, Ruysch, and Albinus (see

Figure 9.2). The exploration of the human anatomy was performed through the art of perspective, autopsy, observation, and demonstration. Nevertheless, the anatomical images were not actually perfect reproductions of the “real” human body, but instead representation of what we envision in our thinking in the confrontation with the outside world.

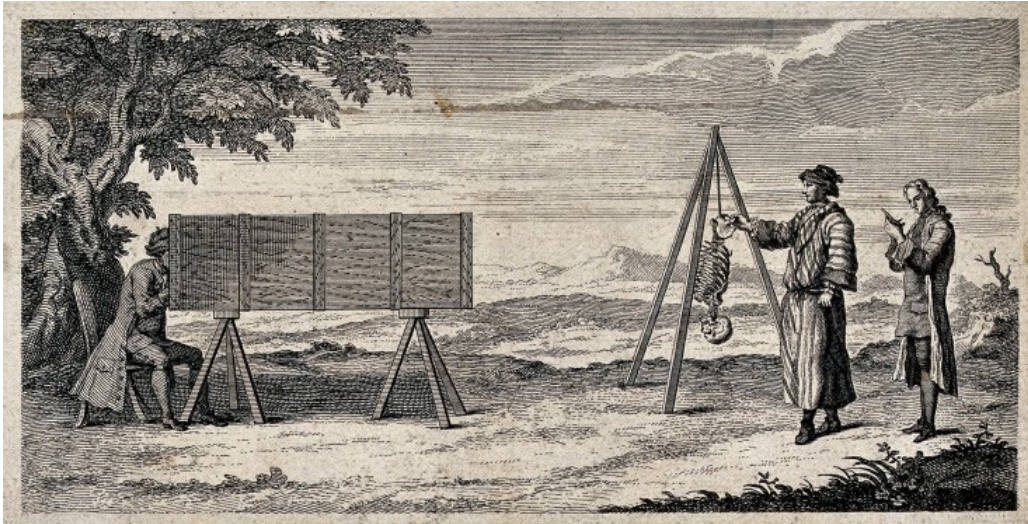


Figure 9.2. The British surgeon and anatomist William Cheselden used a camera obscura to get a realistic picture of the skeleton. The torso is here hanging upside down, to get an upright image in the camera. Frontispiece to William Cheselden, *Osteographia, or The Anatomy of the Bones* (1733).

From the Renaissance onwards, we find an altered vision, which in itself represented a new way of thinking about vision. In the mechanistic natural philosophy, in optics and ophthalmology, the human eye was perceived as a camera obscura. The eye was a dark room where the rays of light from the outside world intruded through the pupil creating an exact replica of the outside world, in exactly the same way as in a camera obscura. In art the camera obscura, for example in the paintings of Vermeer van Delft and Canaletto, created an almost magical realism (Kemp 1990; Hockney 2001). The visual system itself became a camera obscura in the iatromechanical anatomy of the era. One of the first images that directly compared the eye with a camera obscura is found in Lodovico Cardi detto il Cigoli's manuscript *Prospettiva pratica* (1613), and later also in Christoph Scheiner's *Rosa vrsina sive sol* (1626–1630) and René Descartes' *La*

dioptrique (1637). A non-verbal visual thinking in science emerged where imagination created representations of reality. Scientists thought in pictures and created external representations of our inner images. The mechanical models, as well as the camera obscura, acted as a kind of distributed cognition, where thinking took place outside the brain and became strengthened, and was able to come up with new ideas about the world. Science and thinking is not only an interaction between human beings, but it is also an interaction between human beings and their surroundings, between human beings and their machines. What prompted the widened horizons and knowledge of science, which we call the scientific revolution, was probably a strong expansion of new forms of distributed cognition by using and creating artificial objects for enhancing human perception.

9.3.4. Causality: Linking Cause and Effect

Increased, detailed observations of the world, more accurate notes of the seen, longer trips into the known and unknown geography, more numerous data collected from observers and informants, as well as an observance for changes in nature, raised concerns about the relationships between things, a search for the cause of the effect. The causality of nature was not understood as something arbitrary, but was conceived as being based on mechanical laws established by a creator. Changes that we observe have a cause, and cannot happen by chance. The task of the scientist was to find these relationships in the creation. Through observations of changes, early modern scientists saw new causal relations that demanded explanation. By connecting cause and effect in rows of unending causalities, scientists also endowed nature with a narrative structure, formulated a story about the origin of things and the development of nature to the present state. Scrutinising the cause and effect, even though it had been performed in everyday life and in various knowledge endeavours and sign decoding exercises such as astrology, science achieved one of its most celebrated capacities, i.e. the ability to predict the future.

Natural philosophers of the seventeenth and eighteenth century focused their attention on changes in nature, discovered connections between events, tried to understand incomprehensible metamorphoses of nature, and tried to find the relationship between cause and effect, the causality of things. Mechanical metaphors

became useful for describing causalities in nature, how the cause leads to the effect, and how they are parts of a larger whole, a macrocosmic mechanics. Naturalists, geologists, astronomers and others gathered information about natural phenomena, observed, recorded, and saw the events not as unpredictable chances initiated by a capricious god, but as the manifestation of firm principles behind the course of events in the divine plan. The world is not immutable, imperishable, but rather a scene of constant metamorphoses, a permanent impermanence. As Sagredo says in Galileo's *Dialogo sopra i due massimi sistemi del mondo* (1632):

For my part I consider the earth is very noble and admirable precisely because of the diverse alterations, changes, generations, etc. that occur in it incessantly. If, not being subject to any changes, it were a vast desert of sand or a mountain of jasper, or if at the time of the flood the waters which covered it had frozen, and it had remained an enormous globe of ice where nothing was ever born or ever altered or changed, I should deem it a useless lump in the universe, devoid of activity and, in a word, superfluous and essentially nonexistent. [...] Those who so greatly exalt incorruptibility, inalterability, etc. are reduced to talking this way, I believe, by their great desire to go on living, and by the terror they have of death.

In order to deal with the surrounding world, to understand it, and act in accordance with how it works, human beings try to find and detect connections between events. The effect cannot occur by chance, but must be preceded by a cause, and this cause must have meaning. If one could ascertain these relationships and connections between things, if one could identify the causes that lead to a certain effect, one would be able to act in accordance with this and be prepared for what is to come. If it thunders, and then the flash hits the ground, this cannot happen by mere coincidence. There is meaning and reason behind the phenomena. The search for correspondences in nature, connections between events, and the subsequent ability to make predictions about future events is a crucial cognitive prerequisite for human orientation in the world. To interpret the signs of nature, the astrologers' interpretations of the constellations and the motion of planets, the prediction of the future based on signs in the present, the attention to portents that warn humans of approaching events, that accidents are caused by past actions – that is, ideas of causality are grounded in human cognitive abilities.

During the seventeenth century, however, the view on causality changed. Natural philosophers, physicists, astronomers, physicians and other scientists, left a causality

thinking based on correspondences between things, in favour of a mechanical causality. The emerging mechanistic worldview postulated a more material, direct link between cause and effect following the inexorable laws of mechanics. Temporality, that an event followed by another, was insufficient in order to understand causality; rather one should search for the inner mechanical causes that could explain the effect. Instead of assuming correspondences established by God, which were of a spiritual nature, one sought for the causality of the extended substance, matter, aiming at a mechanics of geometry and motion. Strange, unusual events became therefore elusive problems to solve. They needed an explanation. Instead of immediately assuming a supernatural or non-natural cause, one found more and more natural explanations for unusual events. They could be given a natural, mechanical explanation. The task was to find chemical and physical explanations to what had so far lacked natural explanations. The problem became, however, to identify the real, effective signs of nature, the indexicality of things. What phenomena could be understood as indices pointing to their causes? What signs in nature stand in a real, effective connection to what they indicate or refer to? Are there connections between past, present and future events? Can signs in the present point to what has once happened in the past and what will happen in the future?

Fossilised seashells and other animals were found in bedrock, which were sometimes interpreted as sports of nature, *lusus naturae*, but usually explained as remnants of the flood. In 1665, the Dane Nicolaus Steno found shark teeth in the Tuscan mountains, suggesting that where it is now high mountains, had once been a sea (Cutler 2003). Other findings seemed to have no counterpart in the living species. The Linnaean classification of plants and animals on Earth, presented for the first time in Linnaeus' *Systema naturae* (1735), was a way of seeing similarities and affinities between species, which led to attempts in the next century to explain the diversity of species on the basis of a temporal understanding of change, which finally expanded the narrow time boundaries of Bible chronology. Geological time spans increased considerably during the late eighteenth century and the first half of the nineteenth, as geological layers, fossils, and extinct animals revealed the history of the Earth and past epochs (Dunér 2015). By connecting events in a chain of causalities, science is also endowed with a temporal narrative structure (see Chapter 6: Narrativity in this volume) of past events followed by new, and future events. Many grand explanations in science are in such

narratives, for example the big bang of the cosmos, the evolution of life, the rise of civilisation, etc. Narratives of cause and effect place the human being in a temporal story of humankind.

9.3.5. Metaphors: Seeing Something as Something Else

New metaphors were introduced in the seventeenth and eighteenth century, by which scientists and natural philosophers could invent new concepts for describing phenomena beyond the ordinary life, beyond the limits of the human senses. When dealing with things beyond everyday experiences our basic concepts do not work any longer. Conceptualising non-everyday phenomena or abstract ideas requires conceptual metaphors. In order to capture the abstract, we use our experiences of the concrete world. To get to know the unknown, we assume the known. In a broad sense, metaphor can be described as a way to understand and experience something by using something else, as George Lakoff and Mark Johnson (1980) put it, that a structure of a domain is transferred to another, from one source (sensorimotor domain) to a target (subjective experience) that simultaneously preserves the inferential structure. Metaphorical thinking is to create concepts of something in terms of something else. The metaphors function as models for lesser-known things. We transfer knowledge about the known to the unknown, from the familiar to the unfamiliar, from the visible to the invisible, from the everyday world, society, human life, art and crafts, to the inner structure of matter, to the soul and God. Metaphorical thinking is to find similarities between things while maintaining their locational difference, but also to dismiss their deviating qualities, so to generalise and abstract. Many metaphors have their source in the spatial orientation arising from the human body's actions in the physical reality. Seen as an impulsive cognitive mechanism, the logic of these body-based image schemas is used in language and abstract thinking, but also in philosophy, science, and mathematics (Lakoff & Johnson 1999; Lakoff & Núñez 2000).

Characteristic of the mechanistic worldview, as it was formulated in the Cartesian natural philosophy, is the use of metaphors that describe nature as following mechanical laws (Dunér 2013c). The new mechanistic science moved away from anthropocentric, animistic explanations, and instead turned to abstract explanations that were independent of humans. Thus, science underwent some radical changes during the

scientific revolution, and left anthropomorphic metaphors and instead adopted mechanical metaphors. It also introduced a more dynamic view in contrast to the static monumentality of the Renaissance. The technological advances and the success of physics and astrodynamics in explaining the movements of celestial bodies became a model for understanding other phenomena in nature. “The world machine” became the central metaphor in seventeenth and eighteenth-century natural philosophy, a root metaphor that generated new metaphors, new ways of thinking, in particular, spatial and visual metaphors: *space is geometry*, *matter is geometry*, and so on (Dunér 2013d). The human Lifeworld needed explanation, its diversity and hidden connections and causalities, could be reduced to simpler, more confined elements afforded by the new technology, mechanics and geometry of the era. Euclidean geometry gave the world a definite visual metaphorical structure, a world of relationships between points, lines, and circles. The particles of matter, the planetary system, animals and human bodies were machines; even rational thinking became a mechanical process. From a source domain of everyday experiences of machines, these experiences were transferred to a target domain of the less known inner structure of the world of matter.

The scientific revolution also appeared in a time of correspondences, allegories, symbolic, and metaphorical expressions. During the Baroque, metaphors and allegories were highly popular in art, literature, architecture, numismatics, music, and science. Metaphors of the mind could of course be traced back to Antiquity and Middle Ages, to Aristotelian and Christian thinking. A sentient being is a metaphorical thinker, said Aristotle (*Poetics*, 21.1457b6–32), and explained the metaphor as a transfer of a meaning of a word from one object to another. Religious literature is full of metaphors like “the keys of heaven,” “the bread of life,” and “the fire of love.” Gender metaphors were common in the political propaganda. The academic literature utilised metaphors such as the search for knowledge as a journey, the philosophical debate as a fencing duel or a fight on a battlefield, and the truth is brought into light similar to how a gardener peels off the bark of a tree to reach its core, or writing as a textile work that weaves together knowledge. There are numerous examples of metaphors we live by taken from the human Lifeworld. However, they made use of metaphors and analogies as something more than a stylistic, aesthetic decoration. Metaphors could reveal the secrets of creation. Emanuele Tesauro, one of the foremost scholars of the Baroque

period, stated simply that God wrote the book of nature in metaphors, and so it shall be read. The philosopher Giambattista Vico identified in the *Scienza nuova* (1725) four basic tropes. Human thinking had developed from a way of thinking in anthropomorphic fables or metaphors, through metonymy and synecdoche, to reflective thinking or irony. The metaphor was, for him, the ability of the human mind to link objects and events in the world, a way of thinking about unfamiliar things.

In iatromechanics, which was the dominant medical paradigm in the seventeenth and eighteenth century, human anatomy and physiology were described in mechanical, physical, and mathematical terms, taken from contemporary technology and craftsmanship. The human body is a machine. From a cognitive perspective, iatromechanics could be said to be the first system of thought about the human body that consistently tried to leave anthropocentric metaphors. Physics, astrodynamics, statics and mathematics, with names such as Copernicus, Brahe, Kepler, and Galileo, had in the early seventeenth century been successful in describing the world. It was then not far-fetched to try to transfer this aura of order, security, and accuracy that surrounded mechanics, to the chaotic mess of vessels, viscera, and liquids of the human body. If the physical things around us are possible to describe in terms of mechanics and mathematics, what prevents us then from also describing our mortal body in such terms? Important pioneering attempts of a new mechanistic way of looking at the human body was Santorio Santorio's quantitative approach in medicine, the vitalist William Harvey's discovery of the circulation of blood, and Descartes' mechanistic philosophy of nature, his dualistic philosophy, and mind-body dichotomy. The iatromechanistic school of medicine was developed especially in Italy, represented by Giovanni Alfonso Borelli (see Figure 9.3), Lorenzo Bellini, and Giorgio Baglivi. In the early eighteenth century followers of the iatromechanical school could be found all over Europe, and it had become the dominant medical school with the leading name Hermann Boerhaave in Leiden.

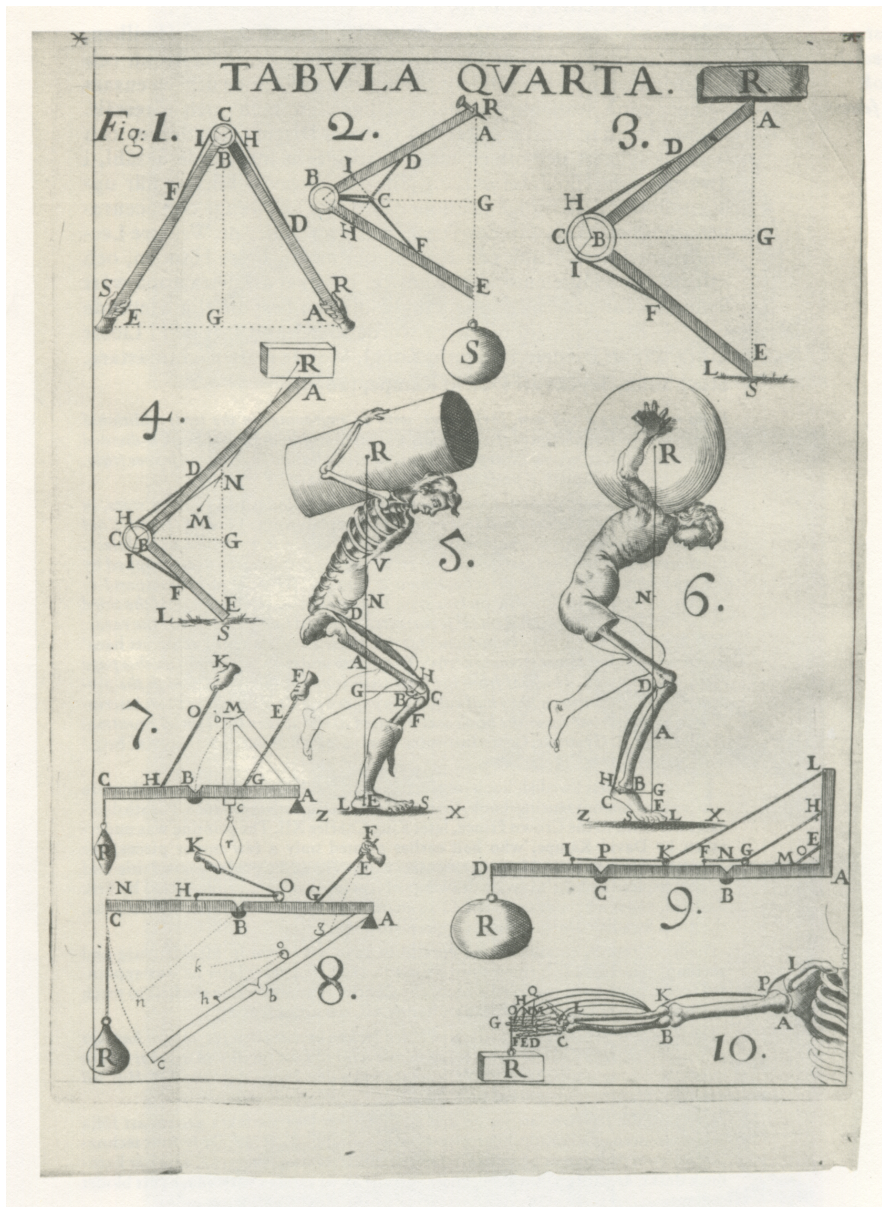


Figure 9.3. The human body can be described by mechanical principles. Joints, arms, and legs act as levers, the muscles as pulling devices. Giovanni Alfonso Borelli, *De motu animalium* (1680–1681).

Iatromechanics was an important shift in the history of medicine, a transition from an animistic thinking where a psychological causality of the physiological processes was applied. Former medical thinking took its departure from a hylozoistic view of nature in which matter was assigned animate properties, where the body was considered as controlled by psychic forces, wills, and spirits. Medicine was strongly anthropomorphic in the sense that the everyday understanding of human actions was

transferred to bodily changes, in other words, in the same way as human behaviour could be understood through teleological explanations, as having goals and aspirations, one could also understand the human body. The bodily functions became animated. The *pneuma* concept in ancient Greek medicine, particularly in the medical theory of Galen, was in itself a metaphor, from a source domain of air, breath, or spirits to a target domain as a living principle in circulating processes of perfection for the functions of the vital organism (Galen 1907; Good 1994). In contrast, iatromechanics instead explained the bodily functions by physical causality independent of psychological forces. For Descartes (1637) *spiritus animalis* became small particles, which mediate sensory impressions through the nerves to the brain, like a liquid through hollow tubes (Hatfield 1992). But the mechanistic explanations could still be easily combined with a belief in a teleology of nature. The divine watchmaker had created everything according to a calculated plan.

The understanding of the human body had thus gone from animism and anthropomorphism to more impersonal physical forces. This was something new in medical thinking. Iatromechanics, understood in a cognitive and cultural-evolutionary perspective, was after millennia of human thoughts on the body, the first system of thought about the human body that consistently tried to deviate from anthropocentric metaphors. It was not the use of metaphors that was new, but the use of new metaphors deviating from the immediate experiences of the human Lifeworld. Iatromechanics tried to find explanations independent of human, spiritual, and divine influences. It was a more abstract way of thinking about the human body. Iatromechanical theory could be a starting point for fruitful scientific inquiry. Mechanical metaphors could lead to a new understanding of the surrounding world. Suddenly it was possible to discover new connections and new “truths” of the natural world.

Metaphors are important in scientific reasoning, and accordingly provide valuable clues to how scientists and philosophers, but also how ordinary people in history thought (Dunér 2014a). Analogies, visual models, and thought experiments seem to be especially common in periods of radical conceptual change (Nersessian 2002; Crane 2010; Olson 1996; Netz 1999; Andersen, Barker & Chen 2006). The specific metaphors of a time are culture-bound variants of the basic metaphors derived from human sensorimotor orientation. The task of the cognitive historian is therefore to study these

trans-historical metaphors and their culture-specific expressions, and to try to find some of the historic people's central metaphors from which they tried to create a consistent worldview or a comprehensive understanding of their Lifeworld.

9.3.6. Categorisation: The Order of Things

A distinctive characteristic of modern science is its systematic approach, its endeavour to find order, hierarchies, and categories. Not least in seventeenth and eighteenth-century science could this endeavour be found, sometimes in the most extreme examples. Categorisation is a fundamental cognitive skill in human thought and perception (Rosch 1975, 1978; Taylor 2003; Gärdenfors 2008). Categorisation is about humankind's eternal quest for order in chaos – an ordered world is easier to live in than a chaotic one. By sorting the impressions from the surrounding world into distinct categories, we are not liable to arbitrary guesses but can benefit from previous experience. One way to make the world intelligible is to try to make it logical, mathematical, and geometric. But the systematisation, categories, regularities, laws, the mathematical description of nature are strictly speaking not out there, but occur in the human mind in its encounter and interaction with the world. They are necessary for the human interpretation of the world, and thus they often tell us more about human beings and their understanding of the world, than about the “real” world itself. It is about creating order, conquering the world and the surrounding physical and social environment with concepts, categories, hierarchies, names, and classes. By dividing up and connecting categories with each other, one achieves a higher order in the chaotic reality. Categorical perception makes the blurred transitions of reality into distinct compartments, adds limits that do not exist, and fills out incomplete patterns. These categories, boundaries and limitations, are to a large extent learned and culture dependent. They do not exactly match actual categories out there, but rather arise in the encounter between human consciousness and its surroundings. They allow us to see some things and not other things, let us see connections and similarities between things. As such, categorisation is an essential cognitive tool in the scientific exploration of the human Lifeworld.

The travels to foreign continents and explorations of the local environment, the closer observation of the surrounding world and the increasing number of collected

specimens, forced the naturalists to construct a system in order to handle the new information, to organise the impressions, to categorise and classify, to create order out of chaos. Knowledge of natural things was gathered with feverish activity. Everything – words, thoughts, plants, stones, and so forth – should be systematised and placed in their proper containers. It was a categorisation of reality, consisting of categories of thought that arise in the interaction between the human mind and the world. During the seventeenth century and onwards, with names such as George Dalgarno and John Wilkins, there was a search for an ideal universal language that could be understood by all humans, irrespective of ethnic origin, culture, education, or language (Knowlson 1975; Strasser 1988; Eco 1993; Rossi 2000; Dunér 2013b). There was a search for a language with fixed meanings and immutable concepts, a longing for clarity, an eternal world independent of humans, a language that reflected the true structure of reality. It was the dream of the calculus, the computing machine, that the world consisted of distinct parts that could be combined in countless combinations.

Categorisation of nature, as in Linnaeus' systematisation and classification of plants and animals, is an excellent example of the human ability to categorise things in interaction with sensory experiences of the surrounding environment. Linnaeus sought for an inclusive hierarchical system of all plants and animals in which each species had its specific essential characteristics. By observing the similarities between things, the Linnaean system paved the way for evolutionary theory. Botany, according to Linnaeus, is classification and naming, to divide and name categories. Naming is central to knowledge. Linnaeus writes, referring to the *Etymologiae* of Isidore of Seville: "If you do not know the name of things, you lose the knowledge of them" (Linnaeus 1751, § 210). He therefore sought a connection between the appearance of a plant (the description) and the name. Linnaean nomenclature is in many ways a kind of a universal language: it should be universally valid, independent of natural languages and cultures, the words should reflect the things, and they should be placed in a hierarchy of categories. In *Philosophia botanica* (1751) Linnaeus organises this classification and categorisation in an all-inclusive system; everything should be described, placed in boxes, and named (see Figure 9.4). Without order and categorisation one can be lost in a terrifying chaos. You need a path, a common thread to follow. "Ariadne's thread in botany is the system, without which chaos will rule," sounds an aphorism of Linnaeus

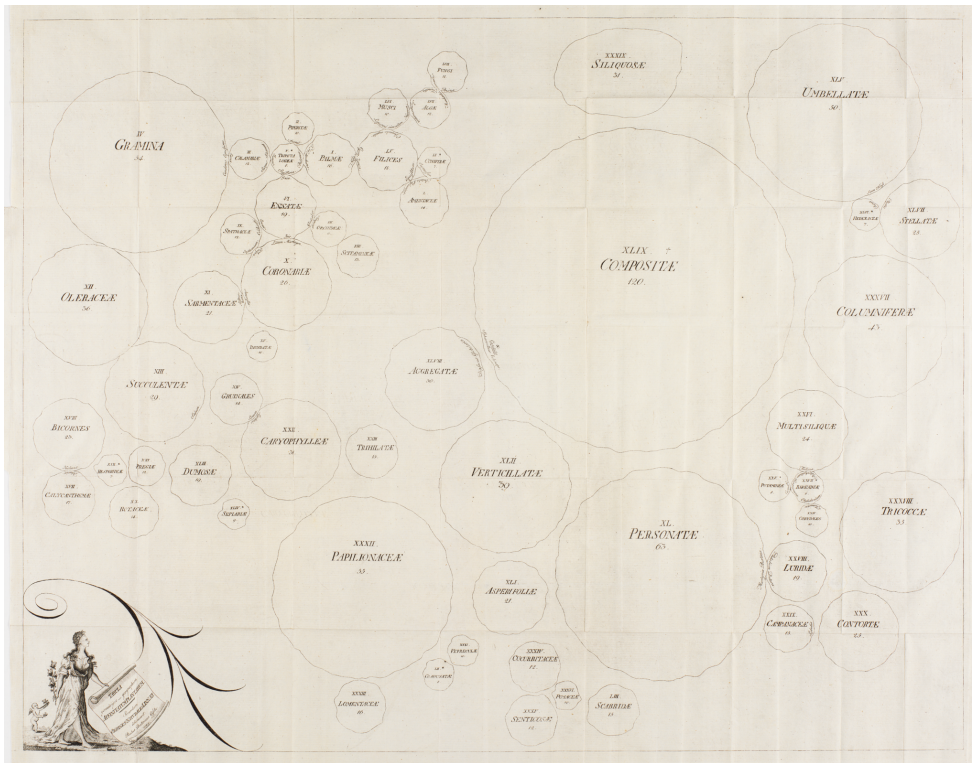


Figure 9.4. A genealogical-geographical map of the kinship of plants according to the system of Linnaeus. The orders appear on Paul Dietrich Giseke's map as round islands in the ocean of nature. The more genera within an order, the larger islands. To the bottom left a putto runs after a barefooted Flora with roses. Carl Linnaeus, *Prælectiones in ordines naturales plantarum* (1792). Photo: Lund University Library.

The discovery of new worlds, the surprising encounters with unknown life forms, challenged the existing habitual categories and classification systems. Exotic objects collected from distant parts of the world, remains from bygone times, fossils, natural specimens, plants, shells, animals, and insects were gathered in private curiosity cabinets, in the collections of academies and universities. The eighteenth century was the century of the systematic spirit. In the introduction to the *Encyclopédie* (1751), Jean le Rond d'Alembert made a distinction between *esprit de système*, the spirit of the system, and the *esprit systématique*, “the real systematic spirit,” which was a reduction of a large number of phenomena to a few principles.

Eighteenth-century science was to a large extent about the order of things, whether it

concerned the material elements, flowers, animals, words, or angels. Everything was included in the large chain of creation, *catena naturae*, everything was part of the universal clockwork, steps on a cosmic ladder. Taxonomy was the science of order, where the whole was analysed into its constituent parts, in order to find similarities and differences, but also to collect things into higher units in a hierarchical system. Classification was a scientific method. Science became a human tool to collect things and make order, and that involves detecting similarities between things, what similarities are considered to be the most important ones, and what things belong together. As Michel Foucault (1966) pointed out, the order of things was an integral part of Western culture, the *episteme* of the time. The division of the world, and the definitions of things, also led to the disqualification of certain phenomena or people from belonging to a particular category. Through history we can find how people have classified, created categories and hierarchies between concepts, objects and phenomena, for example the division of people of different races, ethnic groups and social classes, or animals and plants in kingdoms, genera, and species. Naming of plants and animals has also, according to Londa Schiebinger (2007), been a way to master and acquire new worlds. However, the categorisation was not merely, as it is often portrayed in social constructivist approaches, an exercise of power, a human construction for political purposes. From a cognitive-historical perspective I would add that the human ordering of things has a much more fundamental cognitive foundation. Human beings must categorise in order to be able to think. The classifications of plants and other objects in nature, as well as human categorisations of people and social groups, are parts of a universal human categorisation of the human habitat, as a way to cope with the surrounding environment, the Lifeworld, to orientate in it, and understand it.

Studies of how people classify natural things in history and across cultures can provide inputs to their worldview and way of thinking (Malt 1995; Ranta 2000). The scientific classification is not detached from human culture, neither from how people actually think. Instead of only dwelling on the differences between peoples and cultures, the cognitive historian can also search for similarities in thinking, and study the interaction between cultural and trans-historical factors. There are, undeniably, important cultural differences in how people categorise, but also similarities. Ancient, medieval, and renaissance classifications of plants show striking similarities with those

from Central America, the Middle East, China, and India (Lévi-Strauss 1962; Atran 1990; Berlin 1992). The common denominator is that the classifications of organisms are composed of hierarchies of classes included in each other. Both folk taxonomy and scientific classification assume that all living things consist of natural “groups within groups.” All cultures seem to have specific concepts of biological species, they have a sequential naming based on morphological regularities, they have higher groupings of animals corresponding to the classes of zoology, as well as higher groupings of plants which are not consistent with botanical taxonomy, but have an obvious ecological significance such as grasses and trees (Atran 1990). Historically, when grouping animals and plants, people have focused on their salient features, what they look like, how they behave, what environment they live in and, not least, from an instrumental anthropocentric perspective, how useful or dangerous they are. The specialised, scientific classification, such as the Linnaean systematics, is in agreement with, and is a further development of, this common human way of categorising natural objects.

There seems to be some consistency between folk taxonomy and Linnaean systematics (Coyne & Orr 2004; Atran & Medin 2008). People, no matter from what culture or historical period, find specific biological patterns, which roughly correspond to perceptually noticeable species or genera in scientific taxonomy. The folk taxonomy is an empirical approximation of the scientific, but, at the same time, it adds greater weight to size and characteristics that depend on local and ecological circumstances. Linnaeus also actually dismissed size, dimensions, and occasional local characteristics in his classification, and thus took a step towards a more abstract scientific approach. Linnaean systematics is, one could say, an intuitive species categorisation based on folk taxonomy extended to a worldwide universal system in a methodical and rational way. This universal pretention explains why he also needed a collection of material as rich as possible, from the most distant corners of the world. A famous example, challenging the categories of zoological systematics of the eighteenth century, was the platypus (*Ornithorhynchus anatinus*), an egg-laying, duck-billed, beaver-tailed mammal apparently a fusion of distinct, separated categories (Eco 1997). Linnaeus’ *systema naturae* should be valid everywhere and for everything. The human capacity, the one that Linnaeus to a large extent possessed, to understand and try to categorise and arrange the discontinuous in the living world, is a cognitive prerequisite for scientific

systematics. The hierarchical Linnaean system, with its five levels from Kingdom to Species, is rooted in the hierarchical disposition of the human mind, which facilitates memory and action in the world.

Human beings' search for patterns, similarities and differences in their Lifeworld indicate a developed ability or desire to classify and categorise things, even in that which appears to be a continuum. The human mind searches for limits, tries to find accumulations or clusters, and to perform a kind of cluster statistical analysis of the continuous (Ridley 1996). Independently of each other, people observe the same species in the wild, suggesting not only that there are "real" clusters out there, but more importantly that our human brains seem to be adapted for a similar perceptual cluster statistics. Human classification of species seems to actually correspond to certain discrete clusters in nature, which may explain the similarities between various folk taxonomies, but it also points to a common cognitive capability that have developed in interaction with the biodiversity of our physical environment. The clusters in the surrounding world have an impact on us, but at the same time our human brains detect and create these categories. The long evolutionary history of the human being has been a constant interaction with the surrounding environment, a coexistence with plants and animals, a life within an immense biodiversity. This fact must have shaped human cognition (Medin & Atran 1999). How human beings deal with the world and nature, what is beneficial or needed for human subsistence, affects how they think about their Lifeworld. For example, folk taxonomy conforms better with scientific taxonomy when it comes to larger vertebrates than to species of minor economic significance. Classification of game that is hunted for food is due to life sustaining necessity better adapted to the "natural" species of nature than the large group of insects that is of comparatively little importance for everyday life.

The cognitive ability to categorise is a prerequisite for the scientific conceptualisation of the human Lifeworld. The emerging scientific systematics decontextualised nature by detaching the species, the animal or plant, from its environment. It could then be collected, measured, described, and compared with other forms of life exempted from the local ecological context or subjective human sensory experiences (Atran & Medin 2008). Linnaean classification of the diversity of plants and animals, its attention to similarities between things, the "kinship" between species,

became a prerequisite for the evolutionary theory of the origin of species presented by Charles Darwin in the next century.

9.3.7. Intersubjectivity: The Collaboration of Minds

Increased contact between people, the social interaction, the growing population, and the urban expansion, travels, trade contacts, social mobility, improved opportunities for the exchange of ideas through books, newspapers, letters, the establishment of societies and academies, led to new challenges for human intersubjectivity. The ability to see ourselves in others, to be able to infer what others feel and think, simply to put ourselves into other inner worlds and see the world through the eyes of others, are important prerequisites for language, communication, social interaction, and thus science.

Intersubjectivity is a cognitive ability for understanding other living creatures, their actions and minds, their thoughts and feelings. As social beings we need empathy, without which we would not be able to successfully recognise others' thoughts and wishes. Without empathy, altruistic behaviour, and intersubjectivity, our social interactions would fail. Creating and sharing representations of other people's mentality, i.e. intersubjectivity, is a crucial ingredient of our inner worlds and a precondition for human socialisation, collaboration and communication (Thompson 2001; Zlatev 2008; Dunér 2014b; and Chapter 1: Lifeworlds in this volume). Empathy, compassion, representations of other human beings' emotions, motives, intentions and desires, their body language, beliefs and knowledge, are impossible without an advanced cognitive ability to understand and imagine other possible worlds and other minds. Cooperation requires advanced coordination of individual persons' inner worlds. Sharing attention, to be able to turn our attention to a common object, is one of the most important prerequisites for the evolution of human thought, language, culture, and science. We learn from each other, imitating each other, with curiosity and interest we are drawn to what others observe and are involved in (see Chapter 2: Mimesis in this volume). Due to this attentional behaviour we can take advantage of other people's knowledge, observations, interpretations, valuations and decisions, but also conform and adjust ourselves to the prevailing social community to which we have a desire to belong.

During the seventeenth and eighteenth century numerous academies, learned societies, universities, and journals were established. Meeting places for exchanging thoughts, such as university buildings, classrooms, seminars, workshops, conferences, board meetings, and scientific journals, certainly play an important role for the development of the intersubjective skills of scientists. Although they have survived since the Medieval period, universities became increasingly important for the exchange of ideas, through lectures, seminars, disputations, dissertations, but also as physical environments for meeting other minds, for quarrels, disputes, conversations, and exchanges of ideas. The number of universities expanded tremendously during the early modern period, and many university buildings and colleges were built and became important meeting grounds for the exchange of ideas. Another important novelty in the organisation of science was the establishment of the first scientific academies, Accademia dei Lincei in Rome in 1603, Royal Society in London in 1660, and Académie des Sciences in Paris in 1666, and many others that followed in the eighteenth century. The scientific academies became significant physical and social environments for intersubjective interactions, for exchanging ideas, for spreading and propagating new theories and knowledge. With printed books that kept the exact wording, letters, circulating manuscripts, pamphlets, and pictures ideas could be transferred from one mind to another, provoking interpretations, and aligning thoughts. Particularly important for science is to find fast and reliable media for distributing new theories and knowledge. In the seventeenth century, the first scientific journals were established with *Journal des sçavans* and *Philosophical Transactions* in 1665, and more than one thousand scientific journals were founded in the next century. How science is organised, in universities, laboratories, buildings, academies, journals, and conferences, that give a playground for intersubjective interactions, is an important clue to the expansion and success of modern science in describing human experience of the world.

The emergence of science can, to a large extent, be explained by how human intersubjective skills interact with a changing physical and social environment. Intersubjectivity is needed in order to understand other scientists' observations, ideas, models, and theories that put the field forward. But it can also explain the conformity of science, its conservative tardiness, the "normal science" Kuhn (1962) talked about.

Scientists are social beings who are interested in being included in the social scientific community rather than to risk being excluded and condemned. Various constructivist approaches, such as the actor-network theory (ANT) and other science and technology studies (STS) and sociological network theories, for example in the works of Bruno Latour (1987), have consistently emphasised the social origin of scientific practice. These social behaviours of scientists, however, have their ground in intersubjective skills and other social cognitive abilities. If we want to understand the sociology of scientific knowledge production, we have to go deeper into the question of what makes socialisation possible in the first place, what cognitive abilities we use in socialising, in collaborations, and in mutual understanding of the other's mind. The most fundamental cognitive skill behind this is intersubjectivity. Modern science is a result of the new arenas for intersubjective interactions that appeared from the fifteenth century and onwards.

9.4. The Enactive Theory of Scientific Evolution

Science has here been rendered as a collective cognitive ability that extends biological or neurological changes in human beings, but also rejecting social constructions independent of the constitution of the thinking subjects' bodies and bio-cultural coevolution. The explanation of the emergence of modern science defended here, the enactive theory of scientific evolution, takes into account the bio-cultural coevolution, i.e. it shows that the emergence of science rests on given cognitive abilities in *interaction* with a changing physical and cultural environment.

A coevolutionary history of science concerns human cognitive processes and their reciprocal encounters with the world. It renders the human being as an historical creature shaped by its interaction with the surrounding world. The cognitive-historical approach to the history of science aims at understanding the cognitive processes behind scientific thinking, not only explaining the content of the scientific works or unearthing the sociology of science. In fact, I think, the cognitive approach can give clues to the latter; various cognitive abilities are used in scientific thinking (as I have tried to show with my examples), and intersubjectivity and other social cognitive abilities are fundamental for social behaviour and interaction. People in the history of science, as well as in the present, use certain cognitive abilities acquired during millions of years of

bio-cultural coevolution. Cultural differences and historical change can partly be explained by the fact that people use these cognitive tools in different ways in interaction with specific temporal and spatial environments. Remnants of these thought processes could be found in the historical sources, in the material culture as written texts, images, and objects. Consequently, empirical research is indispensable in order to access how people in history have acted and tried to understand their particular environment, their time, and culture. There are no shortcuts to the history of science other than reading and pervading the historical remains hidden in labyrinthine archives and libraries. After reading thousands of pages, and with some insight into human cognition, how human beings actually think – a research that we have just seen the beginning of – the historian can ask new questions, and provide new explanations of the history of human thinking. And by getting to know our own thinking and its history, we will understand a little bit more of the world we are a part of.

I think there are at least three outcomes or benefits of a cognitive history of human thinking that takes into account the bio-cultural coevolution of human cognition. The enactive theory of scientific evolution put forward in this chapter is an attempt in that direction. The evolution of science was a result of the interaction between human cognitive abilities (such as distributed cognition, situated cognition, perception, causality, metaphors, categorisation, and intersubjectivity) and a changing physical and social environment. First, this approach connects human thinking with its surrounding space, the physical environment, and places the history of science in a spatial context. Human beings are shaped by, but also shape the space around them. They have adapted, both physically and mentally, to certain environmental conditions. But at the same time they have also adapted the environment to themselves, and have created their own artificial physical and cultural habitats. This constant interaction, through the millennia, with the environment and culture, leads up to what we are today. Cognitive history connects thinking with life. Human thinking and the intellectual history of the human being are not just products of discourses, social networking and political ideologies, but concern what it is to live as a sensible and feeling human being of flesh and blood in a world within time and space.

Second, a cognitive history of ideas also connects the past with the present, and places history in a deeper temporal perspective. Human beings are shaped by their

history, both their cultural and evolutionary history. With deeper knowledge about how people function, we can obtain clues to a broader understanding of human life and thoughts in history. Because we as human beings share the same evolutionary history and the same cognitive abilities, we are also able to understand people in history, to admire Palaeolithic cave paintings, marvel at the stories of the Old Testament, see the clarity of the philosophy of Plato, and be emotionally affected by the love poems of Ovid. People throughout history can speak to us. The similarities between people in history suggest that there are common characteristics that are outcomes of an evolutionary history, which contradicts the view that we are born as completely blank slates (cf. Pinker 2002). It also contradicts the existence of completely insurmountable gaps between thinking beings from different times and cultures. The differences that we see are not there because we think differently, have different cognitive abilities, but because we are situated in different times and spaces. A cognitive history of ideas pays attention to what unites people in history, not only what distinguishes us, i.e. some trans-historical human universals, such as the inevitabilities of life: that we are born, eat, move, rest, love, and die. Such an approach can provide a deeper understanding of the universally human, what it means to be human, and give us keys to an understanding of human thoughts, actions and feelings in history, both in terms of the long lines and the individual moments in the changing history. Human beings are historical creatures.

Third, a cognitive history of ideas could connect and reconcile scholarly historical research with the knowledge production that takes place in other scientific disciplines. By connecting our knowledge, we can arrive at a more complete description of the history of thought. This is also in line with the cognitive-semiotic approach, to fend off both biological reductionism and social constructivism, and find a more fruitful way of understanding the self-conscious, thinking and feeling human being, with a body and senses, living in the world. As new data about human cognition is acquired, our view of the human being will also change. If cognitive science, evolutionary theory and other theories of the human being are valid, they should also be valid for historical research. Such a historical research could provide important and necessary contributions and new empirical data to other scientific disciplines, specifically regarding human beings situated in different temporal and spatial environments and how this influences human

thinking, behaviour and action. Empirical historical research is needed in order to get a complete picture of the human cognitive evolution, to fill in the gap between the Palaeolithic and the postmodern human being. With the emergence of culture, the cognitive evolution of the human being does not take place any longer mainly in the brain, but instead within culture created by human beings, through a cultural-evolutionary process. And the premier objects of investigation for historians are just these, human culture and the cultural evolution of the human being. Science is one of many cultural-evolutionary artefacts created by the enactive human being for the understanding of the enigmatic human Lifeworld.