2. How and Why Does Science Develop?

There are, and have been, many myths about science and scientists. In particular, there are two versions of the myth of the lonely genius. One version stems from romanticism. It regards the brilliant scientist as a man who, in a moment of inspiration, unconditioned by his social setting, creates a new idea that once and for all solves a scientific problem. The other version disregards the surrounding milieu, but stresses a supposedly calm and disinterested use of a rational faculty. Notwithstanding the existence of scientific geniuses, these views heavily underrate the role played by technological, economic, political, social, and cultural circumstances in the development of science. Even though some famous scientists have in fact had the experience of receiving a revolutionary idea like a flash of lightning, it should be remembered that even real light flashes have their very determinate existential preconditions. We would like to propose an analogy between ‘swimming’ and ‘doing research’.

There are bad swimmers, good swimmers, and extremely good ones. But in order to swim all of them need water in some form, be it a pool, a lake, or a sea. Analogically, there are researchers of various capabilities, but all of them need an intellectual milieu of some form, be it a university, a scientific society, or an informal discussion forum. In order to learn to swim one has to jump into the water sooner or later, and in order to learn how to do research, one has to enter an intellectual milieu sooner or later. Furthermore, as it is easier to swim in calm water than in troubled, innovative research is easier in tolerant milieus than dogmatic. Let us end this analogy by saying that some research is more like playing water polo than merely swimming a certain distance.

Louis Pasteur is often quoted as having said: ‘In the field of observation, chance favors only the prepared mind.’ It is a variation of the more general theme that luck is just the reward of the prepared mind. Normally, in order to invent or discover something new, people must be in a state of readiness. Therefore, even seemingly accidental scientific discoveries and hypotheses can be fully understood only when seen in the light of their historical settings.

We will distinguish between the question (i) *how* science develops and the question (ii) *why* it develops, i.e., what causes it to develop.

(i) Does science always accumulate by adding one bit of knowledge to another, or are there sometimes discontinuities and great leaps in which the old house of knowledge has to be torn down in order to give room for new insights? The history of science seems to show that in one respect scientific communities (with the theories and kind of research they are bearers of) behave very much like political communities (with the ideologies and kind of economic-political structures they are bearers of). Mostly, there is an evolutionary process, sometimes rapid and sometimes slow, but now and then there are revolutions. In some cases, historians talk of half a century long extended revolutions such as the first industrial revolution around the turn of the eighteenth century and the scientific revolution in the mid of the seventeenth century. In other cases, such as the French revolution of 1789 and the Russian one of 1917, the revolutions are extremely rapid. In science, most revolutions are of the slow kind; one case of a rapid revolution is Einstein's relativistic revolution in physics.

(ii) When those who search for causes behind the scientific development think they can find some overarching one-factor theory, they quarrel with each other whether the causes are factors such as technological, economic, political, social, and cultural conditions external to the scientific community (externalism) or whether the causes are factors such as the social milieu and the ideas and/or methodologies within a scientific community (internalism). We think there is an interaction but, of course, that in each single case one can discuss and try to judge what factor was the dominant one.

The 'How?' and the 'Why?' questions focus on different aspects. This means that those who think that (i) *either* all significant developments come by evolution *or* all significant developments come by revolutions, and that (ii) *either* externalism *or* internalism is true, have to place themselves in one of the four slots below:

	Pure *evolutionary* view	Pure *revolutionary* view
Pure *internalist* view	1	2
Pure *externalist* view	3	4

We want everybody to think in more complex terms, but we will nonetheless for pedagogical reasons focus attention on merely one or two slots at a time. But first some more words about creative scientists.

2.1 Structure and agency

The discussion between externalists and internalists is a discussion about what kinds of causes, correlations, or structures that have been most important in the development of science. Externalists and internalists oppose the romantic and the rationalist views of the scientist, but even more, both oppose or avoid in their explanations talk of freely creating scientists. This denial should be seen in light of the millennia long debate about determinism and free will in philosophy and the corresponding discussion in the philosophy of the social sciences, which has been phrased in terms of structure and agency. In our little comment we take the so-called 'incompatibilist view' for granted, i.e., we think that it is logically impossible that one and the same singular action can be both free and completely determined.

In our everyday lives, it seems impossible to stop altogether to ask, with respect to the future, questions such as 'What shall I do?' and, with respect to the past, questions such as 'Why did I do that?' Also, it is hard to refrain completely from asking questions that bring in moral and/or juridical dimensions of responsibility and punishment, i.e., questions such as 'Who is to blame?' and 'Who is guilty?' Normally, we take it for granted that, within some limits, we are as persons acting in ways that are not completely pre-determined by genes, upbringing, and our present situation. Implicitly, we think we have at least a bit of freedom; philosophers sometimes call this view *soft determinism*. Science, however, even the science of the history of science, looks for the opposite. It looks for causes, correlations, and structures; not for freedom and agency. When it looks backwards, it tries to find explanations why something occurred or what made the events in question possible. When it looks forwards, it tries to make predictions, but freedom and agency represent the unpredictable.

Disciplines that study the history of science can philosophically either admit or try to deny the existence of agency within scientific research. The denial of agency is very explicit in the so-called ‘strong program’ in the sociology of scientific knowledge (e.g., David Bloor and Barry Barnes), but even historians of science that admit human agency have to focus on the non-agency aspect of science.

Accepting the existence of agency, as we do, social structures have to be regarded as being at one and the same time *both constraining and enabling* in relation to actions. A table in front of you put constrains on how you can move forward, but at the same time it enables you easily to store some things without bending down; the currency of your country or region makes it impossible for you to buy directly with other currencies, but it enables you to buy easily with this very currency. Similarly, social structures normally constrain some scientific developments but enable others. The philosopher Immanuel Kant (1724-1804) has in a beautiful sentence (in the preface to *A Critique of Pure Reason*) captured the essence of constraining-enabling dependencies: “The light dove, cleaving the air in her free flight, and feeling its resistance, might imagine that its flight would be still easier in empty space.” Air resistance, however, is what makes its flight possible. Similarly, brilliant scientists may falsely imagine that their research flights would be easier in a room emptied from social structures and critical colleagues.

It is as impossible in scientific research as in everyday life to stop asking agency questions such as ‘What shall I do?’ Since experiments and investigations have to be planned, researchers have to ask themselves how they ought to proceed. If an experiment does not give the expected result, the experimenters have to ask ‘Did we make anything wrong?’ Agency comes in even in relation to the simple question ‘Is there anything more that I ought to read just now?’ Moral questions always bring in agency. Therefore, agency pops up as soon as a research project has to be ethically judged (see Chapters 9 and 10). Even if the acting scientist is invisible in his research results, his agency is just as much part of his research life as it is part of his everyday life.

2.2 Externalism and internalism

According to the pure externalist view, scientific developments are the results *only* of technological, economical, political, social, and cultural factors external to the scientific community. That such factors play some role is trivially true and easily seen in modern societies. Mostly, the state allocates resources for research; each and every year the government presents a research policy bill to the parliament. Also, many big technological businesses and pharmaceutical companies house complete research departments that can be given quite specific research directives.

The external factor can also be illustrated historically. The ancient river valley civilizations of Mesopotamia and Egypt acquired much knowledge of the movements of the stars. Why? They were agrarian societies based upon well-organized irrigation systems, and they needed an almanac by means of which they could predict the floods. But, in turn, a precondition for a functioning almanac was some knowledge about the positions of the heavenly bodies, i.e., some astronomical knowledge. However, the astronomical knowledge they acquired went far beyond what was necessary for estimating the phases of the year. In these cultures, by the way, there was no distinction made between astronomy and astrology. The constellations of the stars and the planets were also regarded as being of importance for the interpretation and prediction of societal events and relations between humans.

These societies did not have any scientists in the modern meaning. It was clergymen who, from our point of view, were at the same time astronomers. Religion, science, and technology were, we might retrospectively say, tacitly seen as an integrated whole. Therefore, even though the ancient agrarian societies of Mesopotamia and Egypt were not centrally interested in obtaining knowledge based on empirical evidence, they did nonetheless produce such knowledge. It was left to the Ancient Greek natural philosophers (e.g., Thales of Miletos, ca. 624-546 BC) to be the first to adopt an exclusively theoretical and scientific attitude towards knowledge of nature. Yet, astronomy was still intimately related to practical needs until much later. When Ptolemy (ca. 90-168) constructed his theory about how the planets and the stars move around the earth, such knowledge was of importance for sailing. At nights, sailors navigated by means of the positions of the heavenly bodies.

Andreas Vesalius (1514-1564) was the foremost in the first generation of physicians after Galen (129-200) that tried to study the human body and its anatomy in detail; he was also one of the first to present his findings in detailed figures. He got his new knowledge partly from dissections of corpses of executed people. But his scientific curiosity was not the only factor. In the early Italian Renaissance, such dissections became allowed. In order to draw and paint the human body in realistic detail, even artists such as Leonardo da Vinci (1452-1519) and Michelangelo (1475-1564) studied the anatomy of the human body also by means of corpses (Figure 1). Galen had been a physician for gladiators, and he had made public dissections on living animals, but he had not really dissected human bodies.

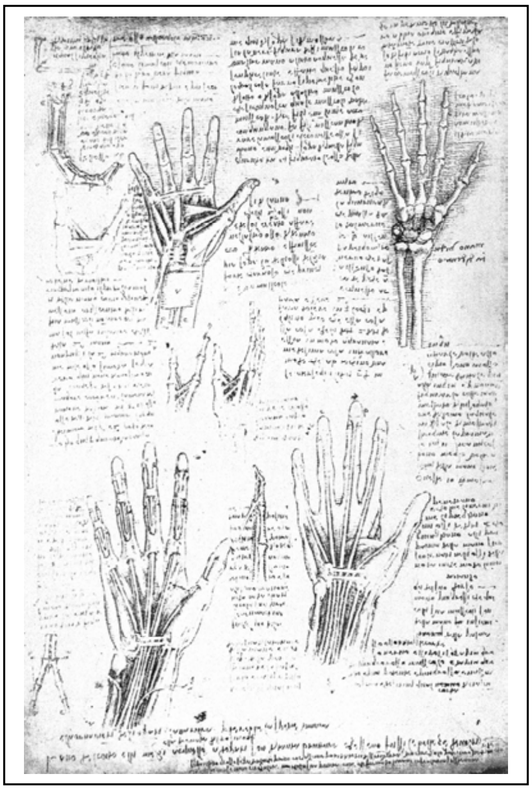


Figure 1: *Anatomical structures drawn by Leonardo da Vinci*

The interaction between external factors and science is easily seen in relation to technology. Just as the emergence of new scientific theories may be heavily dependent on a new technology, new technologies can be equally strongly dependent on new scientific theories. Without the nineteenth century theories of electromagnetism, the inventions of the electric engine and the electric generator are hardly thinkable, and without twentieth century quantum mechanics, the inventions of the laser and some of the modern computer hardwares are hardly thinkable. In these cases, the direction goes from science to technology. But without the eighteenth century invention of the steam engine, the science of thermodynamics would have been next to impossible to discover. Here, the theory that made it possible to explain the function of the engine came after the invention of the engine. Another conspicuous example where a new invention creates a new science is microbiology. Without the invention of good microscopes, microbiology would have been impossible. It should, though, be noted that the microscope was only a necessary condition. It took more than 200 years before it was realized that the micro-organisms seen in the microscopes could be causes of diseases (see Chapter 2.5). The invention of the microscope, in turn, was dependent on a prior development of techniques for cutting glasses.

Back to social structure. During the seventeenth and the eighteenth century, the European universities focused mainly on teaching well-established knowledge. Research, as we understand it today, was not part of a university professor's obligations. This is the main reason why scientific societies and academies, like the famous Royal Society in London, arose outside universities. Eventually, the success of these scientific societies forced universities to change their internal regulations and to integrate research within the teaching task.

According to the pure internalist view, scientific development can be understood without bringing in factors from outside of the scientific community. If agency is admitted into internalism, one can note that some researchers consciously try to *make* internalism true. They try to forbid external views to influence research. As a tumor biologist once said: 'I am not interested in developing new treatments – I am devoted only to understanding what cancer is.' The American sociologist of science Robert K. Merton (1910-2003) imagined a group of scientists proposing in this vein a toast: 'To pure mathematics, and may it never be of any use to anybody.'

Even advocates of pure internalism are of course aware of the fact that, in some way, be it by taxpayers or by firms, full-time working scientists have to be supported financially. With respect to Ancient Greece, this point can bluntly be made by saying that it was slavery that made it possible for interested free men to conduct research. Some outstanding researchers have managed to be both economic entrepreneurs and scientists. According to the pure internalist view, such economic preconditions are wholly external to the way the *content* of science progresses.

In relation to internalism, the Copernican revolution (in which it was discovered that the sun, not the earth, is at the center of the planetary system) has an interesting feature. Copernicus' heliocentric theory had tremendous repercussions on the general worldview and on the various Churches' interpretation of the Bible. However, and astonishingly from an externalist perspective, it had no immediate consequences for navigation techniques (which still relied on the positions of the stars). Despite the fact that Ptolemy's astronomy is based on the false assumption that the sun and all planets are moving around the earth, his theory was at the time sufficient for the practical purposes of navigation. Thus science can progress of itself beyond the contemporary practical needs of society.

The fact that there can be interaction between factors that are external and internal to the scientific community can easily be seen in relation to disease classifications too. Since diseases, and what causes them, figure in many insurance contracts, it can be of great economic importance for many people (a) whether or not their illnesses are symptoms of a disease and (b) whether or not their diseases can be tracked to some specific causes such as accidents or workload conditions. Let us exemplify.

In the 1980s, the American Psychiatric Association declared that there is a certain mental illness called 'post traumatic stress disorder' (PTSD). It was discovered in the aftermath of the Vietnam War, and the diagnosis includes a variety of symptoms such as anxiety, depression, and drug or alcohol dependence. According to anthropologist Allan Young, the symptoms should be considered to result, not from an actual traumatic event, but from the recovered memory of an event. Mostly, the mental breakdown began only when the soldiers came back to the US. It is the delay in reaction to the trauma that sets PTSD apart from the so-called 'shell shock' suffered by many soldiers in the First World War. This classification was wanted not only by the psychiatrists, but also by many veterans and their supporters. Probably, the latter wanted this psychiatrizing of their symptoms not for scientific reasons, but because it meant free treatment and economic compensation.

In retrospect, it is easy to find examples where medical classifications seem to be almost wholly socially conditioned. The once presumed psychiatric diagnoses ‘drapetomania’ and ‘dysaesthesia Aethiopica’ are two cases in point. These classifications were created by the Louisiana surgeon and psychologist Dr. Samuel A. Cartwright in the 1850s. The first term combines the Greek words for runaway (‘drapetes’) and insanity (‘mania’), and it was applied to slaves that ran away from their owners. In ordinary language, the classification says that such slaves suffer from a psychiatric disease, an uncontrollable desire to run away. Dysaesthesia Aethiopica means ‘dullness of mind and obtuse sensibility of body that is typical of African negroes’. It was thought to be a mental defect that caused slaves to break, waste or destroy (their master’s) property, tools, animals, etc. Both ‘diseases’ occurred in the American South, and the diagnoses eventually disappeared when slavery ceased. Similarly, the eugenically based sterilizations conducted in many European countries and in the US in 1920-1960 were more influenced by social ideologies than scientific reasoning. In Nazi oriented medicine, being a Jew was perceived as a genetic disease or degeneration. Homosexuality was in many (and is still in some) countries seen as a psychiatric dysfunction. It is obvious that this kind of disease labeling cannot be understood if one does not take the historical and social context into account. What is mainly socially conditioned in contemporary science is for the future to discover.

The scientific discipline ‘sociology of knowledge’ emerged in the 1920s with works by Max Scheler (1874-1928) and Karl Mannheim (1893-1947), and within it pure externalism has been a rare phenomenon. It was, though, explicitly advocated by some Marxist inspired historians of science in the 1930s (e.g., Boris Hessen (1893-1936) and J.D. Bernal (1901-1971)) and some in the 1970s; Bernal later in his life stressed interaction, and Hessen had no chance to change his mind since he was executed by Stalin. Pure internalism has mostly seen the light in the form of autobiographical reflections from famous scientists, and it has perhaps become a completely outmoded position. But it has been argued even among contemporary philosophers of science (e.g., Imre Lakatos, 1922-1974) that it would be a good thing to write the history and development of science *as if* it was a case of the application of one overarching methodology.

2.3 Evolution and revolution

According to the pure evolutionary perspective, scientific knowledge *always* grows somewhat gradually. However, this succession can be understood in either a Lamarckian way (new features are added/acquired and then inherited by the next generation) or in a Darwinian way (new features come by mutation and survive if they fit the surrounding better than the competitors). Positivism has the former view and Karl Popper (1902-1994) the latter (see Chapters 3.4 and 3.5, respectively). The 'surrounding' is constituted by both competing theories and empirical observations. All kinds of evolutions, Popper claims, can be seen as processes of trial and error where only the fittest survive. That is, both amoebas and scientists learn by trial and error; the difference between them is mainly one of consciousness. This difference, however, brings with it another and more important difference. Often, an animal or a species dies if it fails to solve an important problem, but a researcher who fails does not normally die, only his hypothesis does.

A scientific revolution is not like a mutation adapting to an ecological niche or a change of some epigenetic conditions. It is more like a radical change of the whole ecological system. The worldview, the fundamental values, the way of conducting research, and the way of thinking and presenting results are changed.

The development of natural-scientific knowledge during the seventeenth century is often referred to as 'the scientific revolution'; the emergence of the social sciences and the 'scientification' of the humanities take place mainly in the twentieth century. The scientific revolution brought with it a new view of nature and, consequently, new requirements on explanations. Since nature was no longer regarded in itself as containing any goals, teleological explanations came in disrepute. Explanations, it was claimed, should be made in terms of mechanical interaction, and laws should be stated in terms of mathematical relationships. 'The book of nature is written in the language of mathematics', as one of the great inaugurators of the scientific revolution, the physicist Galileo Galilei, claimed. With the emergence in 1687 of Isaac Newton's book *Philosophiae Naturalis*

Principia Mathematica the revolution was completed in physics. Nicolaus Copernicus (1473-1543) was a famous forerunner, and apart from Galileo Galilei (1564-1642) and Isaac Newton (1643-1727) we find physicists (astronomers) such as Tycho Brahe (1546-1641) and Johannes Kepler (1571-1630).

The scientific revolution was not confined to physics. Starting in the Renaissance, revolutionary changes took place even in medicine. Andreas Vesalius (1514-1564) and William Harvey (1578-1657) were key agents. Men like Claude Bernard (1813-1878), Louis Pasteur (1822-1895) and Robert Koch (1843-1910) might be said to complete this more extended revolution.

The anatomical work of Vesalius paves the way for Harvey's new physiological theories. Also, Vesalius reinstates the importance of empirical observations in medicine and, thereby, indicates that the old authorities, in particular Galen, had not found all the medical truths, and that these authorities had even made great mistakes. This is not to say that Harvey's theory of the circulation of the blood lacked empirical problems. For example, how the blood managed to circulate through the tissues in the periphery (the capillary passage) of the vessel system was still a mystery. It was only solved later by Marcello Malpighi (1628-1694) who, in 1661, with his microscope, managed to observe the small vessels (capillaries) between the arterial and the venous sides of a frog lung. And it was not until oxygen was discovered at the end of the eighteenth century, that the combined heart-lung function could be fully understood. (We will discuss Harvey's scientific achievement more at length in Chapter 4.8).

The post-medieval revolution in physics and medicine went hand in hand with a radical re-thinking in philosophy. Very influential was the French philosopher René Descartes (Latin: Cartesius, 1596-1650), who claimed that all animals are just like machines, that the human body is also merely a machine, but that (in contradistinction to bodies of animals) it is connected to a soul. Souls have consciousness and free will; they exist in time but are completely non-spatial. Despite their non-spatiality they can interact with 'their' human body in the epiphysis (the pineal gland); and in some way a soul can even permeate 'its' body.

According to Cartesianism, apart from actions and events caused by free will, all internal bodily functions and externally caused bodily behavior should be explained the ways machines are explained. To Descartes, this means explanations by means of mechanisms where the movements of some parts cause (push) other parts to move in a certain way. All teleology, i.e., everything that has to do with goals, purposes, and design, was removed from the body as such. The clockwork became rather quickly a metaphor for the description and explanation of internal bodily processes (Figure 2). Its purpose, to show what time it is, is externally imposed on it by its designer and users. Once in existence, a clock behaves the way it does quite independently of this externally imposed purpose. Similarly, Cartesians thought that God had designed the human body with a purpose in mind, but that nonetheless the internal functioning of the body should be purely mechanistically explained. It was not until the Darwinian revolution that the concept of a godly or a pre-given natural design left biology for the purely causal concept of 'natural selection'.

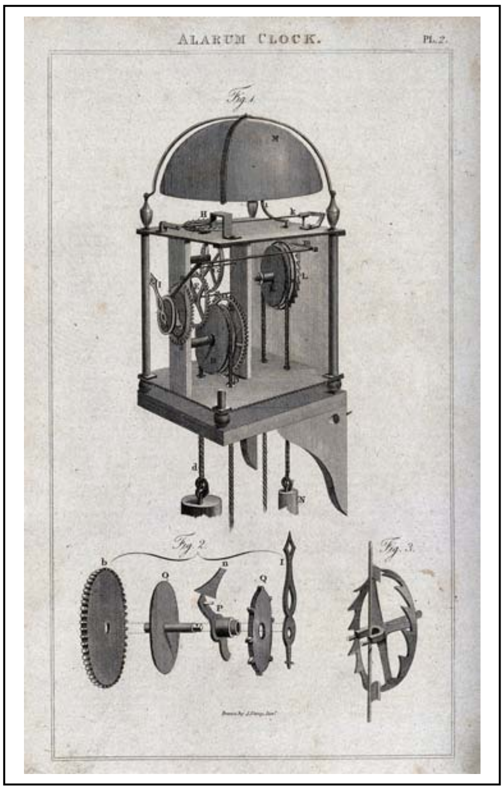


Figure 2: *With its cogwheels, the clockwork early became a metaphor for the mechanistic worldview.*

2.4 The concept of paradigm

After the demise of modern positivism in the 1960s, two philosophers of science came to dominate the Anglo-American scene, the Austrian Karl Popper (1902-1994) and the American Thomas Kuhn (1922-1996). Popper defends a non-positivist but evolutionist perspective, whereas Kuhn stresses revolutions; some of Popper's other views are presented later (Chapters 3.5, 4.2, and 6.3). Kuhn's most famous book has the title *The Structure of Scientific Revolutions* (1962). He divides scientific developments into two kinds, revolutionary science and normal science; in the latter the development is evolutionary. Crucial to Kuhn's position is his concept of paradigm, and we will use this section to explain it. In normal science a paradigm is taken for granted, in revolutionary science one paradigm becomes exchanged for another. Kuhn was an historian of physics, and he claims that the concept of paradigm is needed if one wants to understand the history of physics. In our opinion, the concept can also be applied to the history of medical science. As a matter of fact, using examples only from the history of medicine, the Pole Ludwik Fleck (1896-1961) put forward ideas similar to those of Kuhn before Kuhn. Fleck's most famous book has the title *The Genesis and Development of a Scientific Fact* (1935). Instead of *paradigms* and *scientific communities* he talks of *thought-styles* and *thought collectives*.

Before we continue with our exposition of paradigms, we ask the reader to bear in mind that our presentation brackets the conflict between epistemological realism (the view that we can acquire at least partial knowledge of the world) and social constructivism (the view that all presumed knowledge pieces are merely human conceptual artifacts). This issue will be dealt with in Chapter 3.5. Let us just mention that Fleck is a social constructivist, Popper an epistemological realist, and that Kuhn is ambiguous. In the best-seller mentioned, Kuhn says: "I can see in their [Aristotle, Newton, Einstein] succession no coherent ontological development. […] Though the temptation to describe that position as relativistic is understandable, the description seems to me wrong (Kuhn 1970, p. 206)." In a late interview he says:

> I certainly believe in the referentiality of language. There is always something about referential meaning involved in

> experience that tells you whether it is used to make true or false statements. There is a sense, a deep sense, in which I absolutely believe in the correspondence theory of truth. On the other hand, I also believe it's a trivial sort of correspondence (Kuhn 1994, p. 166).

When in what follows we talk about Kuhn, we will disambiguate him as a realist; social constructivists, on the other hand, try to disambiguate him as being one of them, even as one of their founding fathers.

According to social constructivists, we cannot come in contact with nature at all; according to Popper and Kuhn, we can never come into contact with nature by means of a purely passive reception. Popper calls such a passive view of mind a 'bucket theory of the mind', i.e., he thinks that minds should *not* be regarded as empty buckets that without any constructive efforts of their own can be filled with various kinds of content. Popper's and Kuhn's view is instead that, metaphorically, we can never see, take in, or 'receive' nature without artificially constructed glasses. In science, these glasses consist of partly unconsciously and partly consciously constructed conceptual-perceptual frameworks; outside science, our cognitive apparatus makes such constructions wholly without our conscious notice.

This constructive view brings with it an epistemological problem. Even if one finds it odd to think that *all* the features observed through the glasses are effects of the glasses in the way colored glasses make *everything* look colored, one has nonetheless to admit that in each and every singular case it makes good sense to ask whether the feature observed is a glasses-independent or a glasses-created feature. In fact, when telescopes and microscopes were first used in science, optical illusions created by the instruments were quite a problem. According to the Popper-Kuhn assumption, whereas ordinary glasses can be taken off, the epistemological glasses spoken of can only be exchanged for other such glasses, i.e., there is no epistemologically direct seeing.

Continuing with the glasses metaphor, one difference between Popper and Kuhn can be stated thus. Popper thinks it is rather easy to change glasses, whereas Kuhn thinks that old glasses are next to impossible to take off. Scientific revolutions are possible, he thinks, mainly because old scientists have to retire, and then youngsters with glasses of a new fashion can enter the scene. This difference between Popper and Kuhn reflects different views of language on their part. Kuhn has a more holistic view of language meaning than Popper, and he thinks that meaning patterns are in their essence social phenomena. Popper gives the impression of believing that it is rather easy to come up with new semantic contents and by means of these make new hypotheses, whereas Kuhn's view (with which we agree) implies that this cannot be so since the new concepts should (a) conceptually cohere with the rest of the scientists' own conceptual apparatus and then also (b) to some extent socially cohere with the rest of his scientific community.

Kuhn distinguishes between two parts of a paradigm: (1) a disciplinary matrix and (2) exemplars or prototypes. A disciplinary matrix consists of a number of group obligations and commitments; to be educated into a researcher within a scientific community means to be socialized into its disciplinary matrix. These matrices have several aspects. One is the rather explicit prescription of norms for what kind of data and problems the discipline should work with. These norms answer questions such as 'Can purely qualitative data be accepted?', 'Are mathematical models of any use?', and 'Are statistical methods relevant?' In the history of medicine, this part of the disciplinary matrix is easily discernible in the microbiological paradigm that arose at the end of the nineteenth century; we are thinking of Robert Koch's famous postulates from 1884. In order to prove that a specific microorganism is the cause of a specific disease, four norms, says Koch, have to be adhered to:

i) the specific microorganism must be found in all animals suffering from the specific disease in question, but must not be found in healthy animals;
ii) the specific microorganism must be isolated from a diseased animal and grown in a pure culture in a laboratory;
iii) the cultured microorganism must cause the same disease when introduced into a healthy animal;
iv) the microorganism must be able to be re-isolated from the experimentally infected animal.

The other aspects of the disciplinary matrix are called ‘metaphysical assumptions’ and ‘symbolic generalizations’, respectively. According to Kuhn, even the basic empirical sciences have to contain assumptions that are not directly based on their experiments and observations. The reason is that experiments and empirical data gathering are only possible provided some presuppositions. Such non-empirical presuppositions do therefore often, says Kuhn, take on the appearance of being definitions and not laws of nature, which means that they also seem impossible to contest. If empirical results contradict them, the natural response is to question the accuracy of the observations and/or the researcher’s skill, not these basic presuppositions. If they are quantitative relationships, they can be called symbolic generalizations. Think of this view: ‘necessarily, velocity equals distance traversed divided by time used’, i.e., ‘$v = s / t$’. Does it state a natural law or a definition? Can we even think of a measurement that could falsify this functional relationship? If not, shouldn’t we regard it as a definition of velocity rather than as a natural law? According to Kuhn, Newton’s three laws of motion were once regarded almost as by definition true; it was, for instance, unthinkable that the second law could be falsified. This law says that the forces (F) acting on a body with mass m and this body’s acceleration (a) are numerically related as ‘$F = m \cdot a$’. To Newtonians, it had the same character as ‘$v = s / t$’.

In order to appreciate the point made, one has to bear a philosophical truth in mind: *necessarily, there has to be undefined terms*. The quest for definitions has to come to an end somewhere – even in science. If one has defined some A-terms by means of some B-terms and is asked also for definitions of these B-terms, one might be able to come up with definitions that are using C-terms, but one cannot go on indefinitely. On pain of an infinite regress, there has to be undefined terms, and the last semantic question cannot be ‘how should we *define* these primitive terms?’ but only ‘how do we *learn* the meaning of these undefined primitive terms?’ The situation is the same as when a child starts to learn his first language; such a child simply has no terms by means of which other terms can be defined.

What Kuhn calls metaphysical commitments may take on the same definitional character as symbolic generalizations do, but they are not quantitative. They can be views, he says, such as ‘heat is the kinetic energy of the constituent parts of bodies' and 'the molecules of a gas behave like tiny elastic billiard balls in random motion'.

Whatever one thinks about the particular cases mentioned above, it is true that it is impossible to get rid of non-empirical presuppositions altogether. Assume that someone claims (as traditional empiricists and positivists do) that all knowledge apart from that of logic and mathematics has to be based solely on empirical observations. How is this claim to be justified? Surely, it cannot be justified by observations alone.

A disciplinary matrix with its methodological norms, symbolic generalizations, and metaphysical commitments tells its 'subjects' how to do research, with what general assumptions the objects of investigation should be approached, and what can count as good explanations.

What then are exemplars or prototypes, the other part of a paradigm? Kuhn has a view of language and language acquisition that in some respects is similar to Ludwig Wittgenstein's (1889-1951) later language philosophy. We learn how to use words mainly by doing things when talking and by doing things with words. There is no definite once-and-for-all given semantic contents of words. In order to learn even scientific terms such as those of Newtonian mass and acceleration, one has to *do* things with these terms. One has to solve theoretical problems and/or conduct experiments with their help. In isolation from such situations a formula such as '$F = m \cdot a$' is merely a mathematical formula that has nothing to do with physics. An exemplar is a prototypical example of how to solve a theoretical or experimental problem within a certain paradigm. In order to understand assertions made within a paradigm, one has to learn some of its exemplars. In order to understand an obsolete scientific theory, one has to understand how it was meant to be applied in some crucial situations.

Medical people familiar with learning diagnostics can perhaps understand Kuhn's point by the following analogy. At first one learns a little about the symptoms of a disease (the meaning of a scientific term) by looking at pictures (by having this meaning explained in everyday terms), after that one improves this learning by looking at typical real cases (exemplars) and, thirdly, by working together with a skilled clinician one becomes able to recognize the disease even in cases where the symptoms of a certain patient are not especially similar to those known from the medical textbooks and the typical cases. Good clinicians are able to transcend the learning situations, and the same goes for competent language users. They are able to use their competence in completely new situations. Exemplars, and what one learns through them, cannot be reduced to systems of already defined terms and verbally explicit rules or standards.

Having distinguished between the exemplars and the disciplinary matrix of a paradigm, one should note their connection. Through the exemplars one learns how to understand and apply the terms that are used in the disciplinary matrix. Koch's postulates, for example, are connected with experimental practices, without which they cannot be substantially understood. Koch did not just put forward his abstract postulates he created a certain laboratory practice, too. Over time, the exemplars may change a bit.

Two things must now be noted. First, paradigms and sub-paradigms are like natural languages and their dialects. It is hard to find clear-cut boundaries between a paradigm (language) and its sub-paradigms (dialects) and sometimes even between one paradigm (language) and another. But this vagueness does not make the concepts of paradigms and languages meaningless or non-applicable. Rather, they are impossible to do without. Second, the glasses metaphor has at least one distinct limit. Whereas colored glasses color everything, a paradigm does not. To the contrary, so far in the history of science, paradigms are normally during their whole life-time confronted by some (albeit shifting) empirical data that ought to, but does not at the moment, fit into the paradigmatic framework. For instance, Newtonian mechanics did *never* make accurate predictions of all the planetary orbits. In Chapter 3.5, we will claim that anomalies can, so to speak, be nature's way of saying 'no' to a paradigm.

In Chapter 6, we will present what we take to be the dominant paradigm in present-day medical science, 'the clinical medical paradigm'. Here, we will present the overarching medical paradigm that arose in Ancient Greece and which dominated Europe and the Arab world during the medieval times. Its origin rears back to the famous Hippocrates (460-377 BC). But its most prominent figure is the Roman physician Galen (131-200), hence its name: 'the Galenic paradigm'. Another possible name would be 'the teleological four humors paradigm'.

Why do organs such as livers and hearts behave the way they do? A typical explanation in Ancient times referred to the goals or purposes of the organs. This is the way we normally explain actions of human beings: ‘why is he running?’ – ‘he is trying to fetch the bus’. The action is explained by the existence of a goal inside the acting person. In Galenic explanations, it is as if the organs have inside themselves a certain purpose. Such a view was made systematic already by the Ancient Greek philosopher Aristotle (384-322 BC). According to him, even if some things may be merely residues, most kinds of thing have a certain ‘telos’, i.e., something ‘for the sake of which’ they are behaving as they do when they are functioning properly. The world view was teleological not mechanical. It was thought that nature does nothing without some kind of purpose.

According to Galen, the body contains four fluids and three spirits (Latin ‘spiritus’ and Greek ‘pneuma’), which are distributed via the blood vessels - the veins and the arteries. The fluids are: sanguine, yellow bile, black bile, and phlegm. Sanguine originates in the liver, where material from the intestines, i.e., originally food, is converted into blood. If there is too much sanguine fluid, the surplus is transformed into yellow bile. Black bile is useless sanguine, which is collected in the spleen. Phlegm is associated with the brain. The spirits are: animal spirits (Greek: ‘pneuma psychikon’), vital spirits (‘pneuma zooikon’), and natural spirits (‘pneuma physikon’).

Animal spirits are produced in the brain, distributed along the nerves, and their functions (goals) are related to perception and movement. Vital spirits are produced in the left part of the heart, and they are distributed in the body by means of the arteries. Their function (goal) is to vitalize the body and to keep it warm. Natural spirits are, like the sanguine and yellow bile, produced in the liver, and they go with the liver created blood first to the right part of the heart; their function (goal) is to supply the organs and tissues with nutrition.

The bloodstream (containing all four fluids) is assumed to move in the veins as follows. It goes from the liver to the right part of the heart (see Figure 3 below). Then it moves (but not by means of pumping) out into the rest of the body (organs, extremities, and tissues) where it is absorbed. It moves as slow or as fast as it is produced in the liver and absorbed in the body. The vital spirit is (according to the Galenic paradigm) created in the left part of the heart as a combination of blood from the right side of the heart (assumed to penetrate via tiny pores in the wall of the heart, the septum) and air from the lungs (assumed to arrive in the left part of the heart via what was referred to as the vein like arteries – today we define these vessels as veins: vena pulmonalis, as the direction of the bloodstream in these veins go from the lungs to the heart).

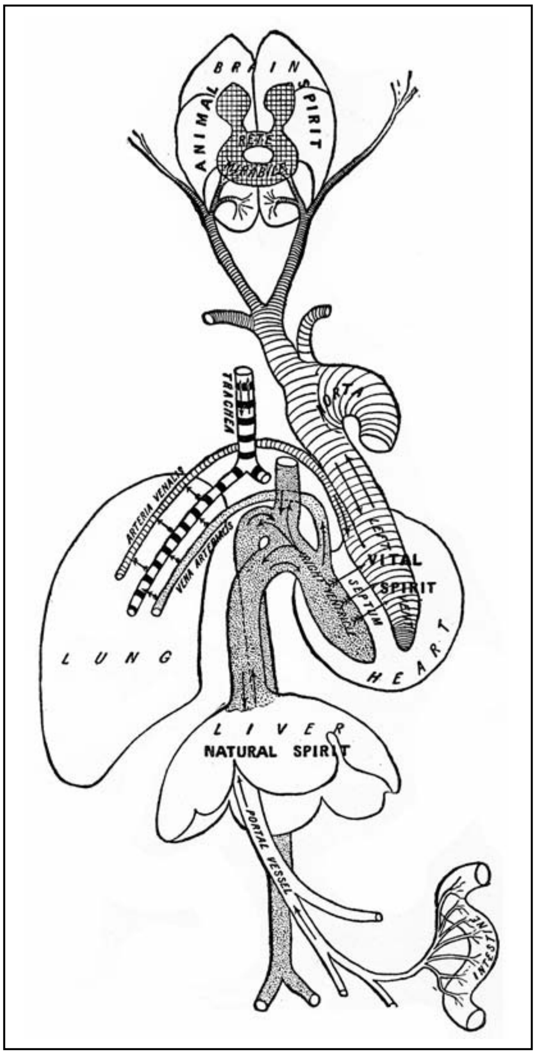
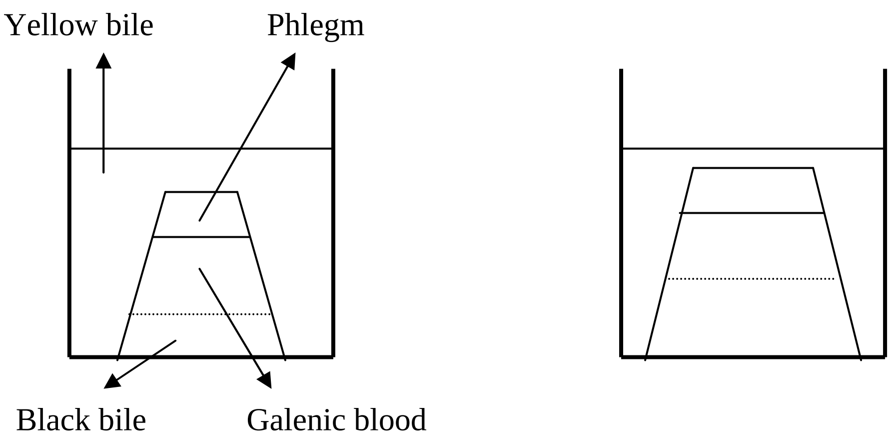


Figure 3: *Here is the Galenic model for the movements of the blood. ‘Spiritus animalis’ was assumed to be produced in the brain, ‘spiritus vitalis’ in the left part of the heart, and ‘spiritus naturalis’ in the liver.*

One goal of the whole body is to try to keep the amount of the four fluids in a certain balance. Stable unbalances explain psychological character traits (temperaments) and accidental unbalances explain diseases. Sanguine persons have too much sanguine or Galenic blood (Latin for blood: sanguis), choleric persons too much yellow bile (Greek: chole), melancholic persons too much black bile (Greek: melas chole), and phlegmatic persons too much phlegm (Greek: phlegm). The way to cure a disease is to restore balance. Sometimes, the body tries (and often succeeds) to do this automatically; as for instance when we are coughing up phlegm. Sometimes, however, the balance has to be restored artificially by a physician. Independently of which of the fluids there are too much, the cure is blood letting. Bloodletting automatically excludes most of the fluid of which there is too much.

This ‘four humors (fluids) pathology’ is not as odd as it first may seem today. The Swedish medical scientist, Robin Fåhraeus (1888-1968), the man who invented the blood sedimentation test, has suggested that the true kernel of this doctrine might be understood as follows – if it is accepted that the four fluids could be mixed in the blood vessels. If blood is poured into a glass jar, a process of coagulation and sedimentation starts. It ends with four clearly distinct layers: a red region, a yellowish one, a black one, and a white one (Figure 4, left). There is a reddish column in the middle and upper part of the jar; it might be called sanguine or ‘Galenic blood’. As we know today, it consists of coagulated red blood cells that permits light to pass through. The lowest part of the same column consists of sediment that is too dense to permit light to pass through. Therefore, this part of the column looks black and might be referred to as the ‘black bile’. On the top of the column there is a white layer, which we today classify as fibrin; it might correspond to Galen’s ‘phlegm’. The remaining part is a rather clear but somewhat yellowish fluid that surrounds the coagulated column in the middle. It might be called ‘yellow bile’, but today we recognize it as blood serum. But there is even more to be said.

Fåhraeus showed that when such a glass of blood from a healthy person is compared with a similar one from a person suffering from pneumonia (caused by bacteria), the relative amounts of the four fluids differ (Figure 4, right). In the sick person’s glass, the proportions of the ‘black bile’ and the ‘phlegm’ have increased, whereas those of the ‘yellow bile’ and the ‘Galenic blood’ have decreased. Such an observation is some evidence in favor of the view that an unbalance between these four fluids can cause at least pneumonia.



The composition of the four fluids in the whole blood from:
(i) a healthy person (ii) a person with pneumonia

Figure 4: *How blood is stored in different layers when poured into a glass jar. The figure might suggest why Galen thought of diseases as being caused by changes in the composition of the four fluids.*

A scientific paradigm may cohere more or less with a surrounding more general world-view. The doctrine of the four fluids (or humors) and the four temperaments were very much in such conformance with other views at the time (Table 1). Each of the four fluids and temperaments was seen as a combination of one feature from the opposition hot–cold and one from the opposition dry–wet. Furthermore, the same was held true of the four basic elements of dead nature: fire (hot and dry), water (cold and wet), earth (cold and dry), and air (hot and wet).

Planets	*Elements*	*Seasons*	*Fluids*	*Organs*	*Temperaments*
Jupiter	Air	Spring	Blood	Liver	Sanguine
Mars	Fire	Summer	Yellow bile	Gall bladder	Choleric
Saturn	Earth	Autumn	Black bile	Spleen	Melancholic
Moon	Water	Winter	Phlegm	Brain	Phlegmatic

Table 1: *A summary of how the ancient Greeks thought of connections between the macrocosmic and the microcosmic worlds as well as between psychological and organological features.*

The four fluids mentioned were also thought to be influenced by different heavenly bodies and the latter's relative positions. Blood was supposed to be controlled by Jupiter, the yellow bile by Mars, the black bile by Saturn, and the phlegm by the moon. An unfortunate planetary constellation was assumed to cause diseases by creating unbalances between the four fluids. Think, for instance, of the old diagnostic label 'lunatic'. Observe that, just like the moon, several mental illnesses have cyclical phases.

Galen had made extensive and significant empirical studies. For example, he had compressed the ureter in order to show that the kidneys produce urine. He even made public dissections of living animals. Such empirical and experimental research was not continued during the medieval ages. Instead, the doctrines of Galen became dogmas canonized by the church. During the medieval era, roughly, medical researchers sat in their chambers studying the writings of Galen trying to develop it only theoretically. But in the sixteenth century some physicians started to criticize the doctrines of Galen – if only in an indirect way.

We have claimed, with Kuhn, that paradigms have a special inertia because of the holistic and social nature of conceptual systems, but more straightforward external causes can help to conserve a paradigm, too. Figure 5 below illustrates a typical fourteenth century anatomy lesson. In an elevated chair we find the university teacher. He is elevated not only in relation to the corpse but also in relation to the students, his assistant teacher (demonstrator) and the dissector (or barber). The teacher is reading aloud from Mondino de' Liuzzi's (1275-1326) compendium *Anathomia* (1316); primarily it is composed of the writings of Galen on anatomy, which contains few and very simplistic pictures. The demonstrator is pointing to the different organs and structures while the teacher is describing them from the text; the dissector is cutting them out. As explicitly stated by one of Vesalius' contemporary colleagues from Bologna, Matthaeus Curtius (1475-1542), it was beneath the dignity of teachers to approach the corpses. This attitude went hand in hand with the view that it was also unnecessary for already learned men to study the corpse – Galen had already written the description needed.

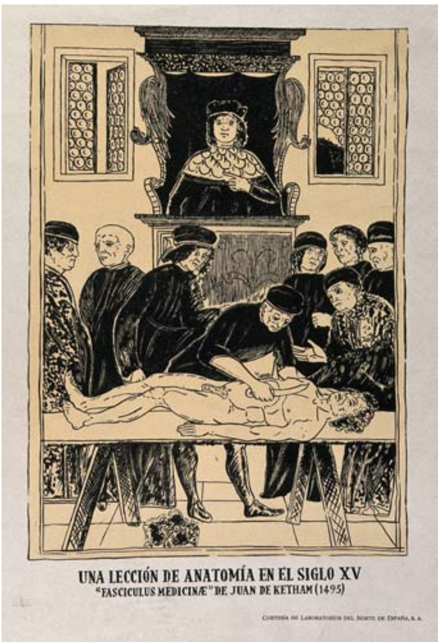
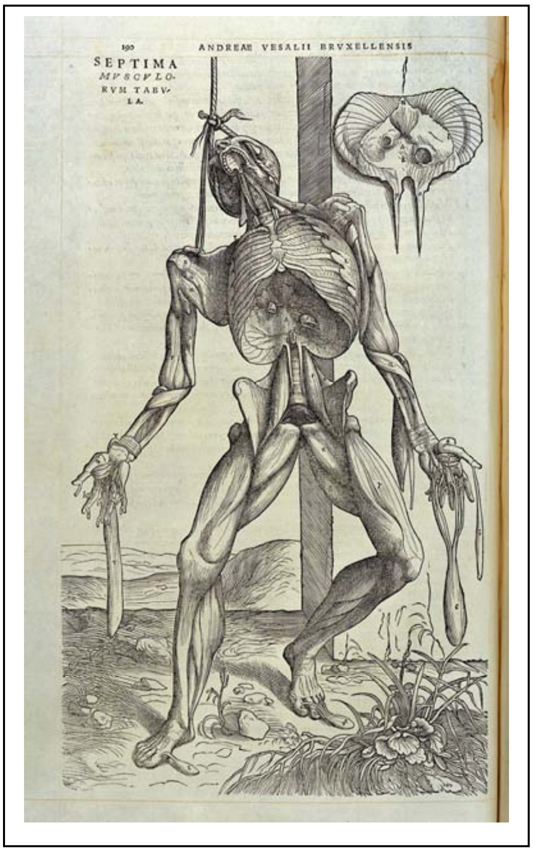


Figure 5: *A medical teacher reading aloud from a compendium. To the right of the picture we find the demonstrator, and in the middle we see the dissector with his knife. All the others are medical students.*

Seen in its historical context, a seemingly simple act performed by Vesalius shows itself to be consequential. Vesalius did not care about the social dignity of the medical teachers; he began to make dissections himself. He wanted to study the human anatomy more systematically, more carefully, and in more detail than before. Also, his anatomical drawings set a precedent for future detailed and advanced anatomical illustrations (Figure 6 below).

When the Galenic paradigm was first questioned, it was so deeply integrated into both the worldview of the church and the values of the secular society that it was hard to criticize. Nonetheless the Galenic views were shown to be confronted by obvious anomalies. According to Galen, there are pits in the walls between the right and left side of the heart. Vesalius stated that he was not able to observe them. Nonetheless, neither Vesalius nor his contemporary and subsequent colleagues made any head-on attack on Galen. The medical revolution started in a gradual way. Even William Harvey, who a hundred years later discovered the blood circulation, avoided being directly critical of Galen. In fact, often he tried to strengthen his arguments by saying that his view was also Galen’s view.



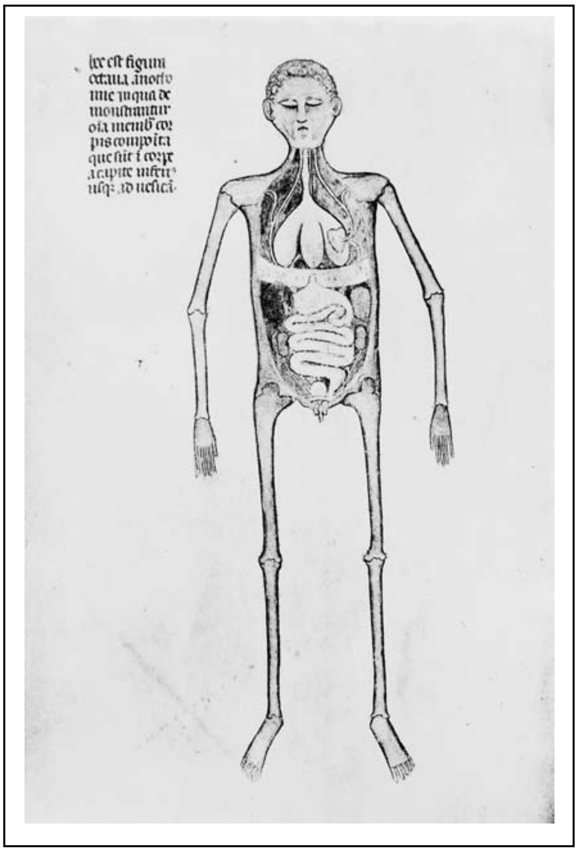


Figure 6: *The left picture from Vesalius’ “De humani corporis fabrica” is considerably more detailed than the right one from the compendium of Mondino (1316). The latter is primarily a summery of Galen’s anatomical writings, which did not contain any illustrations. Mondino, who held a position at the University of Bologna, was one of the first to present anatomical pictures.*

Independently of each other and before Harvey, the Italian anatomist Realdo Colombo (1516-1559) and the Spanish anatomist Miguel Serveto had observed what we call lung circulation (or the ‘small circulation’). But according to Galen there is blood merely in the vein system and in the right side of the heart. The arterial system was supposed to contain a composition of air from the lungs and blood penetrating from the right part of the heart via tiny pores in the heart wall – creating spiritus vitalis. The windpipe (trachea) was also classified as an artery and was supposed to be directly connected with the arterial system through the lungs.

2.5 Generating, testing, and having hypotheses accepted

Many empirical scientists find it easy to distinguish between a first stage of research where they are merely thinking about a problem, which one day ends when they find or create a hypothesis that might solve the problem, and a second stage in which they are testing their hypothesis. This experience is in some philosophies of science elevated into an important distinction between two kinds of research contexts, 'the context of discovery' and 'the context of justification', respectively. Positivists and Popperians (see Chapters 3.4, 3.5, 4.4 and 6.3) claim that the philosophy of science should be concerned only with the context of justification; the context of discovery is, they claim, only of relevance for psychology and sociology of knowledge. In a sense, with Kuhn, we disagree. According to him, a paradigm supplies at one and the same time both a context of justification and a context of discovery. There is an inner connection between these two types of contexts. A paradigm is fertile soil for certain kinds of specific hypotheses while simultaneously justifying the general structure of these hypotheses.

When a paradigm is taken for granted, the development of knowledge is in an evolutionary phase, and in this phase hypotheses do – just like apples – fall close to the tree-trunk. For instance, as soon as the microbiological paradigm was established (at the end of the nineteenth century), the microbiologists rather quickly both discovered and justified many specific hypotheses about different bacteria as being causes of various diseases. As soon as it was *in principle* accepted that bacteria might cause diseases, many such pathogenic agents were isolated rather promptly by means of the microscope and Koch's postulates. Here is a list:

1873	The Leprosy bacterium	Gerhard A Hansen
1876	The Anthrax bacterium	Robert Koch
1879	The Gonococci bacterium	Albert Neisser
1880	The Typhus bacterium	Carl Ebert
1882	The Tuberculosis bacterium	Robert Koch
1883	The Cholera bacterium	Robert Koch

1883	The Pneumococci bacterium	Carl Friedländer
1883	The Streptococci bacterium	Julius Rosenbach
1884	The Staphylococci bacterium	Julius Rosenbach
1884	The Diphtheria bacterium	Friedrich Loeffler
1884	The Tetanus bacterium	Arthur Nicolaier
1885	The Escherich Coli bacterium	Theodor Escherich
1885	The Meningococci bacterium	Anton Weichselbaum
1888	The Salmonella bacterium	August Gaertner
1889	The Ulcus molle bacterium	Augusto Ducrey
1892	The Haemophilus bacterium	Richard Pfeiffer
1894	The Plaque bacterium	A. Yersin & S. Kitasato
1896	The Brucella bacterium	Bernhard Bang
1897	The Botulism bacterium	Emile van Ermengen
1898	The Dysenteri bacterium	Kiyoshi Shiga
1900	The Paratyphus bacterium	Hugo Schottmüller
1905	The Syfilis bacterium	F. Schaudinn & E. Hoffman
1906	The Whooping-cough bacterium	J. Bordet & O. Gengou

Let us now present some aspects of the pre-history of this rapid development. Hopefully, this can give a vivid view of how many presuppositions there are around in empirical science – both for generating and justifying specific hypotheses.

A Dutch lens grinder and drapery tradesman, Antonie van Leeuwenhoek (1632-1723), is often called the father of microbiology. Improving on both existing microscopes and preparation techniques, he managed to see things that no one had seen before. Among other things, he examined material from his own mouth and observed an entire zoo of small living organisms, provided he had not just drunk hot coffee. He reported his observations to the Royal Society in London. At first, his reports were received as simply interesting, but when he reported his observations of microorganisms, which he called ‘animalcules’ (Figure 7), he was met with skepticism. The legendary secretary of the society, Henry Oldenburg (1615-1677), corresponded with Leeuwenhoek and asked the latter to describe his procedure in more detail; eventually a respected team was sent to Holland to check the observations, which they vindicated.

Leeuwenhoek became a famous and distinguished member of the Royal Society, and many persons came to look through the microscopes in order to see this new micro-world; or, by the way, to convince themselves, just like Leeuwenhoek, that the hypothesis of spontaneous generation must be wrong. During the period between Leeuwenhoek and Pasteur, many researchers were preoccupied with observing the microbes. They studied how microorganisms proliferate, whether they occur spontaneously or not, under what circumstances they die, and so on. Microorganisms were observed in infected wounds, but they were for quite a time thought to be the effect and not the cause of the infection. The existence of efficient microscopes was a necessary but not a sufficient condition for discovering bacteria and developing bacteriology.

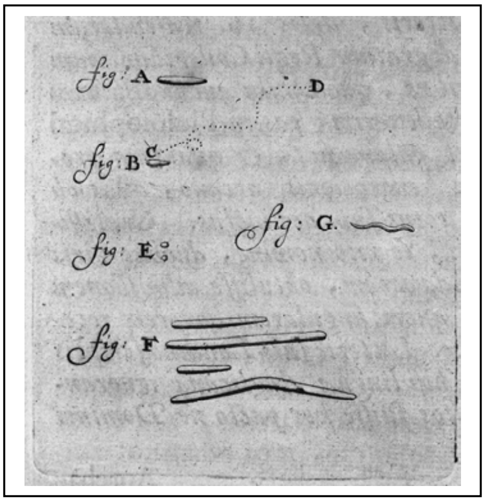


Figure 7: *The picture shows a drawing of Leeuwenhoek’s small animals or ‘animalcules’, which he observed in his microscope.*

During the seventeenth century, Galen’s view that blood is the location of the pathogenesis of diseases dominated, but with respect to fever diseases there were competing theories around; mainly, the contact theory and the miasma theory. According to the contact theory, as the name makes clear, a disease might be caused by means of contagion from a diseased person. For some time, this theory was of great practical importance, especially in Italy and the northern Mediterranean. It was the theoretical basis of the quarantine regulations for merchant vessels. Its popularity started to decrease at the beginning of the nineteenth century. Theoretically, it was hard to explain why some patients became ill and some not, albeit being exposed to the same contagion. Speculating about external factors, one can note that the quarantine regulations were very expensive for the trading companies. ‘Quarantine’ is an Italian word that means forty, understood as the forty days that a ship had to wait before it was allowed to approach an Italian harbor. If no one on board became ill during the quarantine period (mostly, it was smallpox that one was afraid of), it was regarded as safe to let the ship into the port. Viewed from today’s knowledge, it is remarkable how close this quarantine period is to the incubation period for many diseases.

According to the miasma theory, diseases are caused directly by something in the air and indirectly by something in the surroundings. Sick people in slum districts were supposed to have breathed poisoned air, and people living in marshlands were often infected with malaria. ‘Malaria’ is an Italian word that means bad air. In retrospect, it is obvious that the contact theory is more in conformance with modern microbiology, but the miasma theory had many powerful supporters among renowned frontier physicians and scientists at the time. For instance, the German pathologist Rudolf Virchow (1821-1902), strongly rejected the contact theory and later on the microbiological paradigm. His main reason was that microbiology presupposed mono-causality, whereas the miasma theory allowed multi-factorial explanations of diseases to come more naturally.

Among people in the nineteenth century English hygienist or sanitary movement, the miasma theory was popular too. Edwin Chadwick (1800-1890), who was a lawyer and rather skeptical towards the medical profession, maintained in a report in 1842 that the only way to prevent diseases was to eliminate poverty and improve the laboring population’s living conditions, their homes as well as the sewage and garbage collection system. However, in 1854 the medical epidemiologist John Snow (1813-1858), who did not support the miasma theory, presented a report about the hygienic standards around water, in which he claimed concisely that it must have been pollution of the water in one specific pump that was the cause of ninety-three persons’ death by cholera. Snow removed the handle of the pump, the cholera epidemic subsided, and Snow became a hero. Let it be said, that even before his intervention the epidemic had begun to decrease.

Another bit in the medical research puzzle that eventually made Leeuwenhoek’s ‘animalcules’ fit into a contact theory of diseases brings in the English physician Edward Jenner (1749-1823) and vaccination. But before vaccination there was variolation.

From the Arab medicine of the twelfth and the thirteenth centuries, the variolation technique was in the eighteenth century imported into Europe; probably, it was first discovered in Chinese medicine. In variolation, healthy individuals are deliberately exposed to smallpox (variola) in order to become immune. The preferred method was rubbing material from a smallpox pustule from a mild case into a scratch between the thumb and forefinger. Unfortunately the variolation technique was not safe, and it was met by considerable opposition at the time of its introduction. Also, it presupposes contagion as a disease cause.

At the end of the eighteenth century, Edward Jenner introduced a new and safer technique. Jenner was a general practitioner in rural England. He had spent his childhood in the countryside, and among the rural population it was said that milkmaids that had been exposed to cowpox did never get smallpox. A day in May 1796, Jenner tested this layman hypothesis by inoculating material taken from cowpox-infected blisters from a milkmaid, Sarah Nelmes (Figure 8), into an eight year old boy, his gardener's son, James Phipps. The boy got fever for a few days, but was soon healthy again. Today we would refer to this as an immunization trial procedure.

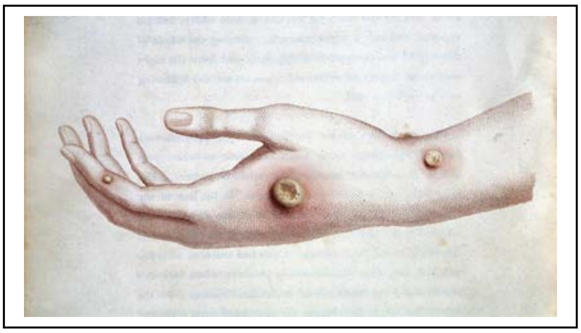


Figure 8: *Cowpox infected blisters from the milkmaid, Sarah Nelmes.*

Six weeks later, Jenner inoculated smallpox material into the boy. Due to the fact that smallpox is rather virulent, one might have expected that the boy would become very ill or die. But fortunately he did not become sick at all. We shall discuss the research ethical aspects of this case further in

Chapter 10. In the present context, we want to stress that although Jenner's experiment supported his hypothesis, he had at first a hard time having it accepted. Being merely a family physician in the countryside, Jenner did not impress his academic colleagues at the universities. But even more, when they tried to repeat his experiment the results were not unambiguous. Today we know that in order to avoid second order effects and erroneous results, the cowpox material must be purified from other microorganisms as well as potentially allergic materials. Otherwise it might result in reactions such as fever, other infections, and skin reactions. Thus Jenner's skeptics had real reasons not to be convinced. However, eventually they succeeded in purifying the cowpox contagion, and the procedure was accepted. Nonetheless, it should be noted, there was still no reasonable theoretical explanation at hand. But the practical use and benefit of the procedure was very significant, especially for the military. At this time, after battles soldiers often died from smallpox or other infections diseases. In 1798 Jenner's 'An Inquiry into the Causes and Effects of the Variolae Vaccinae' was published, and it was soon translated into several languages. Napoleon supported Jenner's views, and had his entire army vaccinated.

Next the most famous man of the contagion story: Louis Pasteur (1822-1895). Pasteur was a chemist, not a physician. But perhaps this made it easier and not harder for him to believe and to show that without microorganisms there are no infection diseases. Since he was not committed to the current medical paradigms, he could conduct his scientific work without the disciplinary matrix of the medical scientific community. It took the latter a long time to accept Pasteur's contributions. It is often the case that anomalies in an old paradigm (here: variolation in relation to the miasma theory) becomes a positive core issue in a new paradigm.

Two events put Pasteur on the right track. First, as a renowned chemist he had been entrusted with the task of examining the fermentation process at a vineyard. Sometimes these fermentation processes did not proceed to the end as expected – and the result tasted bad. Second, he happened to study an epidemic among silkworms.

Unlike many of his chemist colleagues, Pasteur did not find it odd to use a microscope when he studied the wine fermentation process. He made comparative studies of the processes in question, and was able to show that there were living (yeast) cells in the fermentation processes that resulted in normal wine but not in the other ones. Also, he managed to isolate these living yeast cells. He then conjectured that the living fermentation (yeast) cells found are the cause of, or a necessary condition for, the fermentation process. Since the presence of yeast fungi in a vineyard was supposed to kill yeast cells, it ought to be possible to take away the bad processes by reducing the amount of yeast fungi in the tendrils of the vines. So Pasteur did, and good wine production was successfully restored. Pasteur concluded that his hypothesis had been verified, but his colleagues were not convinced.

According to the common view, both microbes and yeast cells were products and not causes of the relevant processes. Yeast cells, be they alive or not, were supposed to play no role in the fermentation process itself. Pasteur turned this picture upside down and claimed that living yeast cells are causes and fermentation an effect.

Fermentation process according to the old theory:

Fermentation process → Living yeast cells
Fermentation process → Dead yeast cells

Fermentation according to Pasteur:

Living yeast cells → Fermentation process is working
Dead yeast cells → Fermentation process is not working

Changing the direction of these arrows was also a precondition for Pasteur's reasoning about infectious diseases. When Pasteur studied the silkworms mentioned, he found a phenomenon similar to that in the fermentation processes. First, using the microscope, he saw a certain kind of microorganism in the sick silkworms that he could not see in the healthy ones. And then he managed to isolate even these organisms. In analogy with his fermentation hypothesis, he now conjectured that it was the presence of these microbes that caused the disease among the silkworms.

Pasteur’s hypothesis was rejected by a number of his influential colleagues. For instance, the German chemist Justus von Liebig (1803-1873) claimed that only enzymes can regulate fermentation processes; even if there are yeast cells they are not able to influence the process. From today’s perspective we can say as follows: Liebig’s hypothesis that it is enzymes that regulate the process is chemically correct, but it is yeast cells that produce these enzymes.

Although the reception of Pasteur’s hypothesis was not in all corners enthusiastic, the time was ripe for his ideas. His hypothesis spread quite rapidly, and several physicians took his ideas into serious consideration. Among the latter were the rural German general practitioner, Robert Koch (1843-1910) and the Scottish surgeon Joseph Lister (1887-1912).

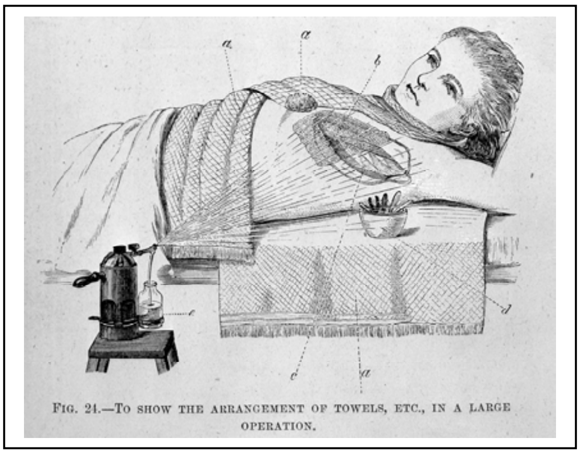
Robert Koch read about Pasteur’s results and began himself to isolate and make experiments with presumed pathogenic bacteria. In his most famous experiment, he infected healthy animals with what is now called anthrax bacteria, which he had isolated from the blood of sick animals, whereupon the infected animals got anthrax. Then, he was able to identify the same type of bacteria in the blood of these artificially infected animals. That is, he really used the ‘Koch’s postulates’ that we mentioned in Chapter 2.3. He showed that it is possible to make animals sick by means of pathogenic bacteria.

Koch’s international breakthrough came some years later when he discovered and isolated the tuberculosis bacteria (1884). The fact that cholera bacteria could cause epidemics supported John Snow’s views and measures in London thirty years earlier. But more was needed in order to establish the microbiological paradigm beyond doubt.

It was the combination of the fruitfulness of Pasteur’s ideas, the carefully conducted procedures of Koch, and the work of their successors in the next twenty years that finally established the microbiological paradigm. But some researchers were die-hards. As already mentioned, the prominent German pathologist, Rudolf Virchow never accepted this paradigm.

An interesting reaction to Koch’s views came from a professor in dietetic chemistry in Munich, Germany, Max von Pettenkofer (1818-1901). He requested a bottle of cholera bacteria from Koch’s laboratory, got it, and then he claimed to have drunk it without becoming ill; thereby saying that Koch's views were wrong. We don't know whether he actually drank it or if he merely cheated.

Another man who read about Pasteur's results, and has become famous in the history of medicine, is the mentioned Joseph Lister. He is the man behind the antiseptic treatments of wounds. After the introduction of anesthesia in 1842, one might have expected that the status of surgery would increase, but this was not unanimously the case. The reason was that the new painless surgery also resulted in an increasing amount of surgical operations – with all the by now well known accompanying complications, especially infections. The mortality rate after amputations was high. In Lister's hospital, sixteen out of thirty-five patients died in 1864-1866. In some other hospitals the mortality rate was significantly higher. Lister learnt from his reading of Pasteur that bacteria might also be found in the air, and he concluded (in a kind of synthesis of miasma and contact theories) that it was airborne bacteria that were the main cause of post-operative infections (Figure 9).



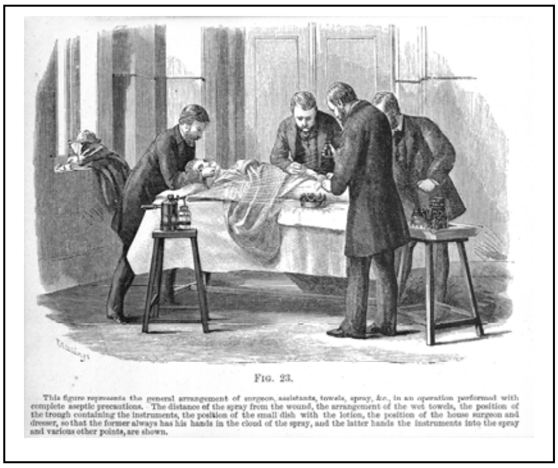


Figure 9: *The left picture shows how the Lister atomizer was supposed to work and the right picture how the antiseptic surgery worked in practice. Notice that the surgeons had no protective gloves and wore their own street clothes.*

In order to prevent pathogenic bacteria from infecting operation wounds, Lister had a carbon acid based suspension sprayed in the operation room – over the operation wound. Apparently he was influencing the air, and accordingly this technology was not in conflict with the miasma theory.

Lister began in 1867, and in 1870 he could report that now only six out of forty patients had died; quite an improvement. Even though Lister's procedure was uncomfortable for the surgeons and all the others in the operation room, his theory and practice were rather promptly accepted.

With these remarks we end our brief history of the emergence of microbiology and the scientific use of the microscope. Later, the microbiological paradigm got its share of anomalies. When the medical community was first faced with the symptoms that we now classify as symptoms of deficiency diseases, the microbiologists continued to search in the microscopes for specific bacteria that might be the causes.

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