What are scientific facts? What are the objects of scientific inquiry?

A philosophical introduction

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The genesis and development of a scientific fact

In 1935, Ludwik Fleck, a Jewish-Polish physician and microbiologist, published *Genesis and Development of a Scientific Fact*. He worked from his experience as a research scientist to argue that scientific facts are produced through social processes, which produce what he called thought-styles in the context of thought-collectives.

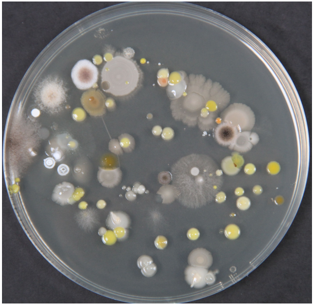
He argued that scientific observations go through stages:

Fleck, *Genesis and Development of a Scientific Fact* (1935)

"(1) Vague visual perception and inadequate initial observation; (2) an irrational, concept forming, and style-converting state of experience; (3) developed, reproducible, and stylized visual perception of form."

Fleck pointed out that often early observations are unintelligible and many early experiments are irreproducible.

Example: Streptococcus



Colonies from a bank note

Fleck and his colleagues noticed rapid growth and unusual pigmentation in a streptococcus (the bacteria associated with strep throat) grown from the urine of a patient.

They decided to carry out a research program to study the germ by growing pure strands of it and using it to inoculate animal subjects.

They quickly noticed, however, that the in addition to the ordinary, yellowish, transparent colonies, there were a few small, whitish, opaque colonies. The study turned into an investigation of variation in the species of the organism.

The earlier and later observations

Initially, the researchers noticed that there was a differentiation of color and transparency. After a number of generations, however, they came to see that they were dealing with variants of structure in which the colonies had, in fact, the same pigmentation.

That is, the difference was eventually understood to be one between smooth colonies and curly colonies. These differences were stable and reproducible, whereas the original observations were not reproducible and it was unclear on what basis they had been made.

Fleck says the observations went through the following stages: (1) the material offering itself by accident, (2) the psychological mood of the investigation, (3) the association motivated by professional habits, (4) the irreproducible initial observations, (5) the slow gaining of experience – learning how to see, (6) the final summarized concise statement of what one has seen.

The problem with "pure" observation

That is, throughout the process of the experimental work, the researchers learn how to see what they are working with, and this learning process shapes what they, in fact, actually see.

Now, perhaps we could try to formulate "pure" observation as simply collecting a list of all the properties we see without any assumptions: diameter: .5–1mm, 2–4mm, …; color 100 (arbitrary scale), color: 80, …, and so on.

But such a list is not possible in principle because (1) such a list of characteristics *already* involves various assumptions and (2) there is no exhaustive list of characteristics. That is, the production of such lists is already determined by the thought-style of the researchers. Finally, (3) discoveries cannot be made by such mechanical procedures.

Solidification of observations in thought-style

Fleck argued that what makes observations clear is the solidification of a thought-style.

Fleck, *Genesis and Development of a Scientific Fact* (1935)

We can therefore *define thought-style as directed perception, with corresponding mental and objective assimilation of what has been so perceived.* It is characterized by common features in problems of interest to a thought-collective, by the judgment which the thought-collective considers evident, and by the methods which it applies as a means of cognition.

The thought-style is what guides and shapes perception. That is, it is only in a particular thought-style that we really see any*thing* at all. This becomes clear psychologically when we find ourselves in a new environment and have a hard time assessing what we are actually hearing and seeing.

Cognition, social activity, and thought-collectives

Fleck argued that cognition is a collective activity. We always have to say "X came to know P in the thought-style S from the epoch E."

Fleck, *Genesis and Development of a Scientific Fact* (1935)

"Cognition … is not an individual process of any theoretical 'particular consciousness.' Rather it is the result of a social activity, since the existing stock of knowledge exceeds the range available to any individual."

Society is organized into various thought-collectives, each with their own special thought-styles: sports, politics, fashion, religion, physics, biology, etc. There are also national and local styles, and so on.

Facts as thought constraints of a thought-collective

Facts will always be related to a particular thought-style.

Fleck, *Genesis and Development of a Scientific Fact* (1935)

"Both thinking and facts are changeable, if only because changes in thinking manifest themselves in changed facts. Conversely, fundamentally new facts can be discovered only through new thinking."

Scientific facts are a sort of *constraint on the thinking of the collective*. Something that is held as a fact, cannot be thought to be otherwise.

The goal of scientific thinking is to increase the total number of thought constraints and limit the amount of *thought caprice*.

When we discover, or learn, a new scientific fact, we must mold our thought in such a way that it harmonizes with the fact.

The interaction of technical with lay concepts

Thought-collectives are organized into inner and outer circles. Most people belong to a large number of outer circles. Experts make up the inner circles. Usually, it takes a long time to get into an inner circle.

Furthermore, thought-styles leave remnants in the common thought-collective. First, there are small, isolated communities which adhere to old thought-styles – for example, astrologers, or practitioners of traditional medicine. Second, every thought-style contains vestiges of the historical, evolutionary development from another style – for example, the invasive concept of disease, or the developmental concept of evolution.

In this way, primitive proto-ideas are often imprinted on fully developed scientific concepts – especially for the lay person, but also often for the expert practitioner. For example, the theory of the pathogenic agent carries a trace of the idea of a demonic invasion, or a disease miasma.

Social constructionism

In the 1970s, social construction became a buzzword for treating a wide range of topics, following Berger and Luckmann's *The Social Construction of Reality* (1966).

While some things are obviously entirely produced by social forces – such as French law, Japanese universities, Cambridge mathematical culture, etc. – social constructionism focuses on things that are usually *assumed* to be natural kinds: gender, race, poverty, literacy, scientific facts, quarks, etc.

Social constructionist scholarship is a kind of *unmasking*. It argues that (1) something that we all assumed to be a essential fact of the world is (2) actually the result of social processes, and (3) *could* be different. It often goes farther and argues that the *constructed kind* is harmful and (4) *should* be different. In this latter form, constructionist scholarship can be *revolutionary*.

Social constructionism in science studies

Some of the strongest cases for social constructionism have been made in the history and philosophy of science.

- L. Fleck (1935) and T. Kuhn (1962) made strong arguments for social constructionism before the term was even coined.

If the structure and content of scientific facts and objects are effected by social forces, then the traditional line between society and nature begins to become blurred.

This realization led to numerous studies which attempted to sort out to what extent the *content* of scientific knowledge itself was determined by society and to what extent by nature.

This became a highly controversial question and led, in the mid-90s, to the so-called Science Wars, which was a *jurisdictional* dispute between scholars in the sciences and in the humanities over who has the right to say what science is.

1: The contingency of scientific knowledge

Ian Hacking (1999) identified three key disagreements between constructionism and realism, claiming that they were ancient.

The first of these is the question of whether or not the content of scientific knowledge is contingent on human culture, or determined by the natural world. We can identify both soft and hard contingency.

Soft contingency, which almost everyone accepts, is the claim that human society develops in a contingent manner and that it could have been that certain theories would never have been developed, or certain facts never discovered. That is, the *questions* we ask about the natural world are contingent. Hard contingency, which is controversial, is the further claim that even under certain theoretical assumptions a totally different sort of science could be produced. That is, even when the questions are asked, the *answers* are contingent.

2: Nominalism or realism

The debate between realists and nominalists goes back at least as far as the Middle Ages.

Realists hope that the natural world has an inherent structure that we are able to discover and describe. They believe that even if we have not got things correct at the moment, that at least in principle it should be possible to do so, because the facts of the matter are simply there to be discovered.

Nominalists, on the other hand, believe that the world is so autonomous, so unique, that it may not even have what we call structure – that all the structure we perceive is simply the structure of our own representations. Our representations are not purely arbitrary, however, they are restrained by the various types of perceptions and experiences we are able to produce, with our bodies or with our material and conceptual tools.

3: External or internal explanations of stability

The debate here is over what causes long-term stability in scientific knowledge: Why do we believe that, for example, (a) Maxwell's equations or (b) the 1st law of thermodynamics are here to stay?

The internalist position is that we believe these are stable claims because they represent true facts about the world, which we have discovered.

The externalist position is that the stability of scientific claims must, in principle, involve elements that are external to the content of science: social and historical factors, interests, networks, and so on. When a new discovery is made, or a new theory advanced, scientists must engage in social engineering, reorganization of vested interests, and the production of new networks of knowledge.

Dolomite

- Dolomite ($CaMg(CO_3)_2$) is a common, porous, semi-crystalline mineral, formed from limestone and closely related to calcite ($CaCO_3$).
- Dolomite is the primary, or sole constituent of marble.
- Dolomite is clearly sedimentary, however, there is still some debate about how this abundant mineral is formed.
- Notice also these different levels of terminology.

A history of its discovery

In 1779, Giovanni Arduino (1713–1795) correctly identified a magnesium limestone, shortly after the discovery of magnesium itself. Arduino also correctly conjectured that the mineral was formed by the replacement of calcium by magnesium in ordinary limestone.

In 1791, Déodat de Dolomieu (1750–1801), who was unaware of Arduino's work, identified a special type of limestone in the Tyrolean Alps (Northern Italy and Austria). He was a leading scholar in the École de Mines, Paris.

In 1792, Nicolas-Theodor von Saussure (1767–1845) incorrectly analyzed the rock and concluded that it was high in aluminum and had no magnesium. He named the mountain range the Dolomites, and the mineral dolomite—after its supposed discoverer.

Experiments on formation

Once it was agreed that Arduino was correct, people began to investigate the chemical processes by which the calcium might have been replaced.

In 1845, Wilhelm Haidinger (1795–1871) produced a reaction between dolomite and gypsum (calcium sulphate, $CaSO_4$) that resulted in limestone and epsom salts ($MgSO_4$).

The reverse reaction, however, requires heat and pressure, and so Haidinger proposed that dolomite must be produced in lower layers of the earth's crust.

In 1847, Adolph von Morlot (1820–1867) produced dolomite synthetically in the laboratory at 250°C and 15atm (14.69psi).

But the vast majority of dolomite appears to have been formed as a sedimentary mineral, on the surface of the earth. So how could it be made without so much heat and pressure?

Uniformitarianism, or gradualism

In the late 18th and early 19th century, there was a growing consensus that forces that produced the geological formations of the past are still at work today. In the early 1830s, Charles Lyell (1797–1875), made a strong case for this principle, which he called uniformitarianism, in his *Principles of Geology*.

Hence, since there are large deposits of dolomite all over the earth, it should be possible to find places of current formation. But this seemed not to be the case.

It became necessary to try to understand if there were past periods of large scale formation, due do varying saturations of magnesium in the ocean waters throughout the history of the earth's formation.

Locations of current formation

It also turned out to be untrue that there is no current dolomite formation, although there does seem to be fairly little. In fact, it is being formed in places rather hostile to most life.

- The arid sands and shallow seas of the Persian Gulf.
- Salt lakes, mud flats, and deep-sea anoxic environments.
- Continental margins of Baja California, and Gulf of California.
- Warm, coastal swamps, such as in Brazil.

Each of these situations appears to have different local mechanisms of formation, and it is difficult to see how these kinds of formation mechanisms could account for the vast deposits of dolomite that are now extant.

“Nanobacteria”

In the 1990s, M. McKenzie and C. Vasconcelos proposed that dolomite was formed by a “nanobacteria” eating the sulphates in limestone, to induce the replacement with magnesium.

“Nanobacteria” were proposed to be bacteria about a nanometer in diameter ($10^{-9} \times 1$mm). (Normal bacteria are about a micrometer in diameter ($10^{-6} \times 1$mm).)

Vasconcelos extracted black sluge from a costal lagoon near Rio de Janeiro, Brazil, froze it and took it back to the lab at the Eidgenössische Technische Hochcschule (ETH), Zurich.

After making a bacterial culture, this was stored at -4°C for a year. On being opened, the product gave an odor of rot, and a knobbly, “organic-looking” growth could be seen with an electron microscope.

What are these things?

In the 1990s, a number of scientists in various fields claimed that they were seeing "nanobacteria" – people found "nanobacteria" in various geological formations, in human and bovine (cow) blood, in a piece of rock from Mars, and so on.

It was proposed that most of the dolomite was formed in the early Proterozoic eon (-2500m – -500m), which is also thought to be the very earliest period of life on earth, and the production of oxygen. Hence, these "nanobacteria" in dolomite, might have something to tell us about the origins of life on the planet.

But many biologists remain skeptical about the existence of "nanobacteria."

It is now largely thought that they are self-replicating structures, but not organic – like a sort of complex crystal.

Dolomite and the three sticking points

We can use the story of dolomite as a model to return to the question of the extent to which it is meaningful to talk about constructionism in the development of scientific ideas.

- That is, to what extent is it meaningful to ask what dolomite is? and in what sorts of ways might we ask this question?
- To what extent does the term "dolomite" point towards a thing that is actually there, in the natural world? Or is it merely an expression for a structure that is locally meaningful to us?
- Finally, is what we know about what dolomite is and how it was formed true, because we have identified a true fact about the world, or because we have a stable system of practices and institutions?

What is dolomite?

When we ask what dolomite is, there may be a number of different ways to ask the question.

- We may be interested in a mineral that has a certain color and texture, or a large-scale structure in a mountain formation.
- We may be interested in a mineral that plays a certain role in the production and storage of fossil fuels (this is one of the reasons that dolomite has been so actively studied), or in the construction of luxurious buildings, and so on.
- We may be interested in the chemical composition of dolomite. Or in the physico-chemical aspects of the process of its formation.

Each of these questions has different answers, and they carve out a somewhat different, although partially overlapping, set of objects.

Does "dolomite" name a natural kind?

When we say the word "dolomite" we point to something in our network of meaning. But what is that thing, and is it something whose structure is fully determined by the world itself?

- "Dolomite" refers to a mineral that is found on the surface of the earth, having certain characteristics and being in certain locations.
- But this "dolomite" is not pure magnesium carbonate, $CaMg(CO_3)_2$. Where is the line between "dolomite" and "limestone," and so on?
- Moreover, "dolomite" is formed by processes that are not fully understood, and may be entirely local. Hence, we may be referring to local varieties.
- That is, "dolomite" may name something that is useful to our sorting of the physical world, but does not correspond to a natural kind that can be objectively defined.

Will our knowledge of dolomite change?

- We have not yet produced an understanding of the formation of dolomite that can be regarded as the established belief.
- We still do not know how so much dolomite was formed in the historical past of the earth's formation.
- What we know is that there are large masses of porous rock that are mostly magnesium carbonate, $CaMg(CO_3)_2$.
    - But what does it mean when we say a certain rock is *mostly* magnesium carbonate, $CaMg(CO_3)_2$? How could there be any grounds for this belief that are not internalist – that is, that are not grounded in our understanding of chemistry?

Overview

- We have looked at some general questions that we can ask about the project of studying history, the history of science, and the history of the earth and life sciences.
- We have looked at Fleck's ideas about the development of scientific facts in the thought-styles of thought-collectives.
- We have looked at Hacking's ideas about the role of social construction in explaining the development of science, using, as an example, scientific discussions of dolomite.