What is a Scientific Fact?

Waseda University, SILS

Omnibus: Invitation to Natural Sciences



A naive view: Facts and theories

A typical, empiricist description of the functions of facts and theory in scientific activity might be as follows:

- Facts are simple observations of the world, and they do not change over time.
- Theories are hypotheses about what these facts mean, or how they should be understood, and they change over time. Theories that have been around for a while, and survived many attempts at falsification can be regarded as robust scientific theories. (This is what distinguishes, say, the *theory of evolution by natural selection* from, say, *my friend's theory about why Americans are so loud*.) But, they may still change over time.

This view supposes that the process of observation is completely straightforward.

We want to step back and *problematize* the notion of scientific fact.

First, let's distinguish between different types of facts.

The most straightforward kinds of facts are things that we see happening. For example, we watch someone drop an apple and assert, "the apple fell to the ground."

Empirical Facts

Empirical facts are things that we can assert about the world based on direct, straightforward observational evidence.

Unfortunately, very few scientific facts are of this kind. Even simple observations may be more involved.

- When we observe something for the first time, we may not know what we are seeing seeing involves *assumptions*.
- When we measure something, what we actually see is a certain set of marks, or movements on our instrument.

Most scientific facts are a combination of observations and other beliefs we have about the world.

Even the idea that the natural world is governed by laws is not something that we can immediately perceive – it has not been universally believed by all rational observers.

Conceptual Facts

Conceptual facts are things that we assert about the world based on strongly held philosophical views that we have about the kind of world in which we live.

Most of the facts that we believe are true are actually conceptual facts.

Even facts for which there is strong evidential support are not understood evidentially by most people, and sometimes turn out, in retrospect, to be incorrect.

The distinction between the two

It is not always possible to clearly distinguish between empirical and conceptual facts. Indeed, most beliefs are based on a mixture of observational evidence and general ideas about the world.

It is better to think of a continuum.

- On the one side, we have things we observe directly: an apple falls down, the moon is seen near certain stars, etc.
- On the other side, we have models that we use to describe the things we see: the apple is in a gravitational field, the moon moves about the earth in a near-circular ellipse, etc.

In between these types of "facts" is a broad spectrum of activity – measuring with various instruments, mathematical modeling, etc.

Scientific activity has to begin with some claims about the evidential basis, the facts of the matter. Establishing these facts is a process that takes place in social, political and intellectual contexts.

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 produced by social forces – such as the French legal system, Japanese universities, the 19th century Cambridge mathematical culture, etc. – claims about social construction focus on things that are *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 an essential fact of the world is (2) actually the result of social processes, and (3) *could* be different.

We can think of *scientific facts* as (a) being claims about real features of the natural world, which we have discovered, and (b) as being the result of the way we organize the world, through social processes.

The genesis and development of a scientific fact

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

He argued that even scientific observations go through various 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*. He argued that what makes these things clear is the solidification of a thought-style.

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, etc.

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.

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 ambient temperature today should be one of the simplest *scientific facts* that we can imagine.

We can look at a thermometer, check our phones, watch TV, etc., and easily find out what temperature it is. We can easily understand the answer to the question, "What is the temperature?"

But, what *is* temperature? From a theoretical perspective, temperature is a measurement of the average kinetic energy of the molecules in an object or system.

Temperature of an ideal gas

Where the kinetic energy of a molecule of gas is $E_k = \frac{1}{2}mv^2$, then temperature, *T*, is related to E_k by the equation $\overline{E_k} = \frac{1}{2}kT$, where *k* is Boltzmann's constant (1.3 × 10⁻²³J/K).

The simple concept of temperature

But we do not need to comprehend any of these concepts to state today's temperature, or to understand something about what that statement means. What do we need? We need a thermometer, and we need to understand how to read it, but not necessarily *how it works*.

A thermometer is a particular type of instrument that is made in order to produce a certain kind of measurement. In order for the measurement to be universally meaningful, it should be standardized in some way, and *people must be educated* so that the standard can be understood, either intuitively or theoretically.

- In order for thermometers to become standardized, they should be based around some points that are naturally fixed.
- In order for us to understand this standardization, we need to distribute both thermometers and their scales, through material networks and education.

The necessity of fixed points

By 1600, Galileo (1564–1642) and others were using *thermoscopes* based on the principle that liquids expand when they are warmed, but they were notoriously unstandardized.

E. Halley, "An Account of Several Experiments ..." (1663)

"I cannot learn that any of them ... were ever made or adjusted, so that it might be concluded, what the Degrees or Divisions ... mean; neither were they ever otherwise graduated, but by Standards kept by each particular Workman, without any agreement or reference to one another."

In the 17th & 18th centuries, there were almost as many fixed points as there were interested natural philosophers.

Fabri: snow and highest summer heat. Halley: deep caves and boiling alcohol. Newton: melting snow and blood heat. Dalencé: ice and melting butter. Celsius: melting ice and boiling water, etc.

Galileo's thermoscopes

Images of a number of the thermoscopes used by Galileo, and a reconstruction of one of them.



Melting ice and boiling water

By the mid-18th century, due to Anders Celsius (1701–1744), a consensus was forming about using the *states of water* as fixed points. But establishing the fixity of these "fixed points" was not so simple.

A.-J. De Luc, Recherches sur les modifications de l'atmosphère (1772)

"Today people believe that they are in secure possession of these [fixed] points, and pay little attention to the uncertainties that even the most famous men had regarding this matter, nor to the kind of anarchy that resulted from such uncertainties, from which we still have not emerged at all."

In 1776, the Royal Society of London appointed a committee, chaired by Henry Cavendish (1731–1810), to look into the fixed points of temperature. They noticed that pressure effects the boiling point, and that temperature varies a good deal between various degrees of boiling. One of the committee members was Jean-André De Luc.

Problems with the boiling point

De Luc, and the committee, noticed that there was a fair degree of variability in the temperature of boiling water depending on various things, such as the type of bubbling, the placement of the thermoscope, the types of material involved, etc.

H. Cavendish, Report of the Royal Society (1777)

"... There was a very sensible difference between the trials made on different days, even when reduced to the same height of the barometer [i.e. the same pressure], though the observations were always made either with rain or distilled water ... We do not at all know what this difference could be owing to ..."

The reading of the same instrument could be made to change depending on a wide range of variables, and sometimes apparently changed independently of the variables. De Luc discovered that under certain circumstances, such as when boiled under oil, or when using cleaner water, the temperature of water could be raised above 100° C before boiling. This phenomena came to be known as superheating.

It became clear that the amount of dissolved air in the water effected the way in which the water boiled and the temperature at which it started to boil. De Luc came up with various methods for removing the air, such as shaking the water, or repeatedly boiling it and then cooling it in sealed containers.

It was found that water that had been purified in this way started boiling as high as 112.2° C and continued to boil with explosive puffing at unsteady temperatures.

De Luc described various different types of boiling.

What is boiling?

- Bubbling: Although this has the appearance of boiling, it is only the escape of dissolved gas, as in fizzy drinks.
- Fast evaporation: No bubbles are formed, but a good deal of vapor and heat escape steadily across the open surface of the water.
- Hissing: Numerous bubbles of vapor rise partway through the body of water, but they are condensed back into the liquid state before they reach the surface.
- Common boiling: Numerous bubbles of vapor rise up through the surface at a steady rate.
- Bumping: Large isolated bubbles of vapor rise occasionally; the bubbles may come only one at a time or severally in an irregular pattern.

Explosion: A large portion of the body of water suddenly erupts into vapor with a bang, throwing off any remaining liquid violently.

The purity of the water, and the air

In the mid-19th century, Joseph Louis Gay-Lussac (1778–1850) noticed that water boiled in a glass vessel at 101.232° C, but adding some iron filings brought it down to 100° C. A number of experiments showed that the water had to be in contact with a solid surface to boil at anywhere near 100° C.

F.M.L. Donny, "Mémoire sur la cohésion des liquides" (1846)

"The faculty to produce ordinary ebullition cannot in reality be considered as an inherent property of liquids, because they show it only when they contain a gaseous substance in solution, which is to say only when they are not in a state of purity."

Only impure water in a slightly dirty vessel would boil around 100° C.

Later, in the 1880s, it was discovered that the air also has to be a bit "dirty" in order for steam to form.

The temperature of steam

A number of experimenters noticed that the temperature of the steam given off by boiling water was more steady than that of the water itself.

Report of the Royal Society (1777)

"The most accurate way of adjusting the boiling point is, not to dip the thermometer into the water, but to expose it only to the steam, in a vessel closed up in the manner represented."

This was reconfirmed in the mid-19th century, when superheating was being studied extensively.



How do we establish fixed points in the absence of any fixed points? If we do not already know that water always boils at a certain fixed temperature, how can we find out whether or not this is the case?

We must have some *independent* standard of judgment. There is no logical way out of this dilemma. Natural philosophers in the early modern period dealt with this problem through instrumentation.

They used thermoscopes built on the *assumption* that liquids change in volume as a linear function of changes in temperature. The problem of fixity was examined with numerous independent instruments.

Thermoscope

A thermoscope is an instrument that registers changes of temperature, but has no fixed, standardized scale.

An Italian thermoscope

A 17th-century theromoscope made in Italy.



The practical problem of fixity

The philosophical problem of fixity was translated into a practical problem. If a number of different people use instruments of various construction, without any clear theory, and they all notice that certain points are more or less fixed, they are fairly justified in believing that there is some real regularity at stake.

They each know that the reading of the thermoscope agrees with their intuitive impressions about temperature and heat. They can coordinate various thermoscopes with one another and get similar readings from similar phenomena. There is a general regularity.

They can read the reports of other researchers, in other parts of the world, using different instruments, and maybe based on different theories, and they all agree in rough outline.

The problem of determining fixed points becomes a problem of *instrumentation* – that is, a matter of making instruments and working with them.

When De Luc discovered that under some circumstances water boils at 101° or 103° C, how did he know that one of these temperatures wasn't actually 100° C? To get out of this *vicious circle*, natural philosophers have to rely on instruments and instrument makers.

For example, Daniel Fahrenheit (1686–1736), a Polish-Danish chemist and instrument maker, built thermometers using a scale such that water, ice and salt = 0° F, the formation of ice = 32° F, and body heat = 96° F. The intervals between these were then divided up, geometrically, and marked on the instrument. These instruments were crude, the top point was not fixed, but it was enough to get started.

These thermometers were well made and they could be calibrated with each other and with thermoscopes, which thus became thermometers. The thermometers were distributed and used, and through these kinds of efforts certain facts about temperature began to be consolidated. By looking at this example we begin to understand how even a simple *scientific fact* is produced by a network. As Fleck argued, *scientific facts* are not the result of an individual making an observation, but are rather the result of various social processes and ways of thinking.

In the case of the debates about temperature in the early modern period, the network consisted of things like people (natural philosophers, instrument makers), the equipment in their labs (thermoscopes, flasks, fire, water, etc.), scientific societies and their committees, journals, ideas about heat, etc.

In the case of today's temperature, it consists of people (scientists, educators, TV weather reporters, you and I, etc.), equipment (standardized thermometers, textbooks, satellites, mobile phones, etc.), institutions (schools, weather agencies, governmental ministries, etc.), laws and agreements, theories of thermodynamics, etc.

Networks in the production of scientific facts

If we think of *scientific facts* as simply unproblematic observations of the way things actually are, it will be difficult to account for the way they change over time. Of course, we could say the old facts were simply wrong, but this still doesn't explain *how* they change.

Instead we may find it useful to think of *scientific facts* as produced and maintained by a network consisting of both human and non-human actors – such as scientists, politicians, consumers, objects, instruments, laboratories, schools, governments, laws, ideas, etc. In the early period of the production of facts, such as we saw in the case of temperature, the network is quite clear. Once a fact is well established, however, the function of the network recedes into the background and the network becomes a sort of black box.

Facts that we consider as unassailable are supported by vast networks that are so complete, so dense, as to almost escape notice.

Overview

- We have looked at some philosophical ideas about *facts*, focusing on Fleck's theory of the birth and growth of *scientific facts*.
- We have looked at the example of the conceptual and social development of the fact of today's temperature.
- We have talked about the construction and maintenance of such facts through the concept of material networks, involving people, institutions and instruments.