

How scientific knowledge comes about –

# Seeking what is true and what is false

**Gerd Friedrich**

**A goal of science is to obtain new knowledge in order to be able to describe reality in the best possible way and to disassociate the truth from falsehoods. However, every new finding obtained through scientific means has to fulfil certain criteria before it can be generally recognized. Just making assertions and to propagate them as being true cannot be taken seriously. Findings must be able to be proven and be able to stand the test of being critically checked and reproduced. Laypersons who are interested often cannot tell how scientific experts from different fields come to the conclusions that some studies are considered doubtful and the findings from others are considered serious and meaningful. The road to scientific findings is paved with concrete data – over many centuries there has been something philosophical about this road leading to the truth.**

Seeking the answer to the question concerning what is true and what is false is as old as science itself and in the past few centuries especially philosophers have discussed which path will lead us to the source of knowledge. Aristotle said, sensory perception is the starting point when seeking new knowledge and knowledge itself results from experience. Through experience assumptions, ideas and hypotheses can be evaluated to determine their degree of truth. He divided science into two branches. One being theoretical science, which only orientates itself towards knowledge and the other, practical science whose goal is to use knowledge in a meaningful way in order to solve problems. Aristotle was of the opinion that from an observation a conclusion followed, and if this could be proven only then could a definition be formulated, in other words a general valid statement.

However, exactly here at this step from conclusion to proof lies a problem that has been puzzling knowledge theorists for centuries. How can proof be demonstrated? If we observe the usual way in which we obtain knowledge, we can establish the fact that we intuitively use an old scientific principle. We make single observations, generalize them and formulate a generally valid statement from our observations. When we have observed three times that a youth has crossed the street when the light is red, we can conclude that all youths today ignore red lights for

pedestrians. When in three out of five years there hasn't been a white Christmas, we can conclude that the global warming has finally put an end to snow in December and that white Christmases will at best remain a memory.

This method is called induction, when from single instances we come to a general conclusion and this is a normal practice in many scientific disciplines. However, opinions are divided on this. According to the supporters of inductivism, science is derived from experience and they emphasize that scientific knowledge is based mainly on induction.

Critics question the inductive method because general statements are made without the evaluation of all individual cases. Hence more is said than what was actually observed. Although it is permissible to make statements about observations, the laws of nature cannot be deduced from them. One who has also observed that blackbirds, sparrows, pigeons and magpies can fly, can make a statement to this effect, but he cannot inductively come to the conclusion that all birds can fly. The problem with proving something inductively is that the knowledge obtained cannot be verified. The statement "all swans are white" can be deduced from a single observation, albeit it cannot be verified since every single swan in the world would have to be observed. Definitions that are established through inductive reasoning do not hold water since the hypothesis is for-

mulated with only a part of what is real, which is then followed by a sweeping statement concerning its validity.

Critics of inductivism have proposed another method. The philosopher Karl Raimund Popper (1902-1994) did not present an observation at the beginning of a scientific finding but rather he presented a problem. In order to solve the problem the scientist has to work out a hypothesis and then its suitability has to be proven during the evaluation process. But the important difference to those who advocate induction lies in the method of evaluation. "General statements about reality are empirically not verifiable but they can be falsified". When applying this to the statement "All birds can fly" Popper would not try to verify this statement with countless examples of birds that are able to fly but would check and see if the hypothesis could be refuted – which can be done with ostriches, emus and kiwis. "Scientific hypotheses are only working hypotheses", concluded Popper from his principle of falsification which states "they are only valid for as long as they hold up against falsification attempts". According to Popper, statements which cannot not be falsified are not scientific. The hypothesis that plants have a conscience cannot be proven as false, so therefore, according to Popper's reasoning it is not scientific. His point of view is as follows: "the more a scientific statement refers to reality the more it can be falsified; if it is not falsifiable, it does not refer to reality".

The way Popper moves in the opposite direction of what the supporters of inductivism proposed. He takes a general statement (all birds can fly) and directs it toward individual observations in order to evaluate hypotheses or to solve a problem. This procedure is called deduction. According to Popper, proof can be empirically demonstrated as it is with the inductive method: he stressed that "experi-

ence alone can decide if a statement is true or false". The deductive method is an important instrument with which prognoses can be deduced from laws or theorems. Popper: "A hypothesis is considered valid when prognoses derived from it are verifiable". Only when a general conclusion can be proven to be correct when applied to an individual case, is the hypothesis correct.

Even before Popper some scientists accepted the deductive method as the only means to obtain findings. The rationalists René Descartes and Gottfried Leibniz saw reason and deductive demonstrations of proof not only as the origins of knowledge but also as methods used for evaluating hypotheses.

In modern science both the principle of induction and deduction are taken up and applied. The starting point of a scientific work is a hypothesis. This can refer to an observation or can be deduced from theories that have already been established. With the hypothesis a prognosis is made, and this is in turn checked with a experiment. "Plants need CO<sub>2</sub> for photosynthesis." From this statement it could be concluded that plants grow more quickly when the CO<sub>2</sub>-content in the immediate area of the plants is increased. However, this conclusion must be checked with suitable experiments to validate this statement. The experiment is decisive for the evaluation of the hypothesis. Therefore, the experiment must be set up in such a way that from the results of the experiment fundamental statements on the hypothesis can be deduced. If the hypothesis states that high frequency electromagnetic fields effect the blood pressure of humans, the scientist must therefore chose an experimental design so that it includes the analysis of the parameter "blood pressure" and the boundary condition "high frequency electromagnetic field" is fulfilled. Moreover, other factors which could falsify the re-

sults have to be excluded. A proband who is under stress could falsify the measurement. An increase in his blood pressure could be caused by the stress he had already felt before the experiment started and not by the electromagnetic field.

The results of the experiment can either confirm or refute the hypothesis. If the hypothetical statement is proven to be falsified by the experiment, then the hypothesis has to be rejected. A serious scientist would accept it if his hypothesis was proven to be false. Provided that the experimental conditions were carefully chosen, he would reconsider his hypothesis and proceed to formulate it anew. A falsification can lead to a new hypothesis, which in turn would have to be evaluated.

If the hypothesis is verified by the experiment the next step is to expound the new finding during the induction process, this means making a generalization. The aim is to make a general statement, in other words to combine a confirmed hypothesis with a theory. The physiologist Ivan Pawlow determined in his experiments on classical conditioning that at first a value-free acoustic signal, e.g. the stroke of a bell, triggered dogs to salivate. But this signal must be first coupled with a direct stimulus which triggers the flow of saliva such as food. Today, classical conditioning is a special learning process which is generally accepted and not only used with dogs. Albeit at first Pawlow could only apply his conclusions to dogs, a generalization applying to all animals would have been false. Also, the generalization that all learning processes are based on classical conditioning is inadmissible. Other experiments done by different scientists have shown that classical conditioning is a common learning principle with animals and humans, but it was also shown that other learning mechanisms are involved in the complex “learning behaviour”. After repeating the experiment and after the

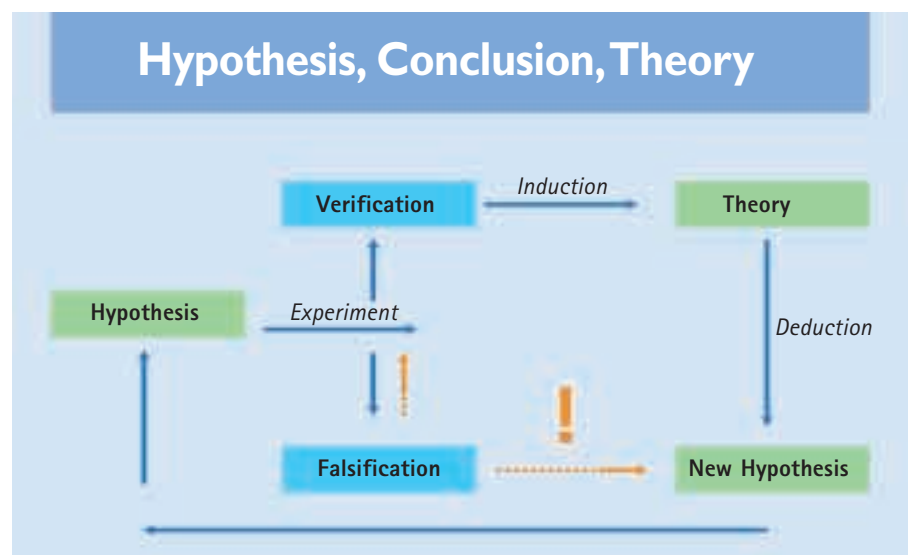
results were reproduced with other animals, classical conditioning could be promoted to the rank of a formal theory. From this theory, then, new hypotheses can be worked out using the deductive method. A new hypothesis could for example state: “classical conditioning can be positively used in personnel management”. This deductive hypothesis, however, would have to be confirmed with suitable experiments.

Problems with induction can still be observed today, for example when results are transferred to other species, with the aim of applying a hypothesis confirmed with animals to humans. Transferring scientific results derived from animals to humans is a form of induction, since the scope of the statement can be expanded. However, in practice this is never done without further proof because the reliability of the induction must be critically questioned and additional experiments may be required. If it is ethically acceptable experiments are carried out on humans, or, whenever possible, other results are consulted for comparison. Albeit research has its limits and a risk will always remain when conclusions concerning animals are applied to humans. However this lies in the

nature of things, in experimental science, as in life, a situation where there are no risks does not exist.

Induction plays, even though it is often criticized, a central role in scientific research and in the meantime there are methods with which individual weaknesses of the induction principle can be compensated for. A significant weak point of the induction method is its conclusion from the particular to the general. Inductive conclusions always have a degree of truth to them but are never considered strictly valid. The degree of truth can be estimated and even increased after carefully planning an experiment and through the use of suitable statistical methods. When the number of influencing factors is low, the final statement is more exact. Statistical procedures as well as a well designed experiment are imperative for the evaluation. With them one can, first of all, determine how many experiments or how many probands have to be used in a series of experiments. Furthermore, statistical procedures can provide more information as to whether a finding resulted from a chance occurrence or if it really reflects reality.

Research findings gain in relevance



when they are evaluated and compared. Experimental conditions have to be chosen and written up in such a way that others will be able to reproduce the experiment so that the same results can be obtained. Demanding reproducibility ensures the quality of scientific research because a hypothesis is only considered valid when its experimental results have been repeatedly reproduced and not proven to be random occurrences.

Results are comparable when they are obtained under the same framework conditions. In the field of biology, for example, the cell lines, mediums, and any other relevant parameters used in an experiment must be identical.

A good research strategy is what the Forschungsgemeinschaft Funk e.V. has been successfully doing for years, and that is the policy that knowledge has to have a broad basis. By conducting studies in five fields, namely molecular, single cells, cell clusters, animals and epidemiology an abundance of data is produced. Every experimental set-up, experimental strategy, measurement values, and conclusions are critically questioned and evaluated by experts and the findings are carefully checked with replication studies. When science is consulted as the basis for value limits or for determining safety limits than high quality standards for the research required is a mandatory prerequisite. Only when the methodology is anchored in a sound foundation, is the knowledge that is built upon this foundation valid and sound.

Gerd Friedrich  
Forschungsgemeinschaft Funk

## Students learn about electromagnetic fields in the environment

On June 17, 2003, the FGF together with the chair for High Frequency Technology at the University of Stuttgart invited the 10<sup>th</sup> grade students from the Erasmus-Widmann Gymnasium Schwäbisch Hall to attend an informative lecture focusing on "EMCE". The pupils are participating in a project with the newspaper Frankfurter Rundschau called "Newspapers in Schools". After a short theoretical introduction, the focus was on interactive team work.

The students, under the direction of experts, were very much involved in being informed about a broad spectrum of sub-