Fantastic Scientific Methods and How They Demarcate Science

Up till now, we've talked about a great many scientific methods, including inductivism, falsificationism, Kuhn's view of normal science and paradigms, Lakatos' research programmes, and Feyerabend's anarchism. In fact, this is the approximate time order by which they are proposed in history. And this is not occasional, which demonstrates how the philosophy of science has progressed over time.

The birth of a more accurate scientific method is often strongly related to the occurrence and solution of further scientific problems. Usually the longer time has passed, the more complicated current problems which need solving are, thus the more advanced method is needed. For instance, we won't expect a method like Kuhn's to be developed during the era of inductivism, for one of the motivations of Kuhn's method is that the previous methods failed to account for many of the crucial episodes in the history of science which had happened after that era, such as the adoption of Bohr's theory. In short, no one can propose a scientific method which transcends the age he lives in too much. While the scientific methods are evolving continuously, the demarcation between science and pseudo-science is reshaped accordingly, and this is the reason why it is closely related to the issues of scientific progress. We'll give a summary for each method in history and describe how they tackle the demarcation problem briefly.

Inductivism

Inductivism is based on inductive logic, one of two distinct logic types. The other type of logic is deductive logic, which is a method of reasoning where the conclusion needs to follow from the premises. A deductive argument is valid if and only if the conclusion must be true when its premises are true, i.e. deductive logic is truth preserving. However, due to its property, deductive logic doesn't allow one to discover new scientific laws but reveal what has already been contained in the premises. Finally, deduction is just a way one uses in reasoning.

Unlike deduction, induction is a process in which a general conclusion is summarized from a finite but adequate number of facts. Based on this, inductivism method can be used obtain new scientific laws. However, inductivism fails to guarantee correctness of them, for they must satisfy all the observations, the number of which is infinite, before they are regarded right. Thus, it's impossible. Besides, circularity is unavoidable during inductive reasoning. To be clear, during such a process new scientific knowledge is supposed to be derived from observable facts, but meanwhile, prior scientific knowledge is used to justify induction itself. For example, one critical problem which confuses inductivism a lot is how induction itself can be justified.

The demarcation between science and pseudo-science given by inductivism is quite simple. A scientific law can be qualified as science only when it has been observed under a wide variety of circumstances, and no exceptions are found. Otherwise, it'll be regarded as pseudo-science.

Falsificationism

Founded by Karl Raimond Popper, falsificationism recognizes the limits of inductivism, and tries to propose a different scientific method, where observations and deduction are of great importance. It claims that whether a theory is scientific or not doesn't depend on how well it interprets the observational evidence, but its falsifiability. Theories that fail to do so should be eliminated. The fittest theory can survive and be the best available theory. More importantly, scientists must follow a method based on conjectures and refutations, which has no end and can promote the progress of science continuously.

According to falsificationism, scientific laws should provide some information about the behavior of the world. The more falsifiable a theory is, the better it is. If it is highly falsifiable and finally resists falsification when being tested, it will be a good scientific theory.

Though it seems perfect, falsificationism still encounters many severe problems. By following the falsificationism method, when a theory contradicts some observations, it'll be falsified. However, the observations themselves are theory-dependent, which means they can be fallible rather than the theory itself. Unfortunately, we have no way to examine it due to falsificationism. A typical case is Bohr's theory of atoms which has been mentioned previously. It was falsified at first, but Bohr showed great confidence and insisted on his theory, and finally it was proven that it is the historical account for the related observations that is wrong. If scientists strictly follow the instructions of falsificationism, such an excellent scientific law will be rejected or neglected. All in all, the status of falsificationism method is challenged.

When it comes to the demarcation of science and pseudo-science, the criterion of falsificationism is more complicated than that of inductivism, but still clear: a theory is science if and only if it's falsifiable, i.e. there are potential tests to falsify it. According to this, Einstein's general relativity is science, while Marxism is pseudo-science, for it is always flexible to accommodate any instance, thus is uninformative in a sense.

Kuhn's Normal Science and Paradigms

Since both inductivism and falsificationism failed to propose a methodology which fully reflects the actual scientific practice as well as describe all crucial episodes in the history of science, Kuhn presented his own account for the development of science through the concept of normal science and paradigms. The motivation of his account is the standpoints that the actual practice of science should be better gained from the sociological analysis of scientific communities, and that it's better to focusing on the revolutionary phases of the historical development of science when describing it.

In Kuhn's view, science is not a cumulative process, so accumulating discoveries and inventions won't really make it progress. Besides, when a new theory replaces an old one, the practitioners of the latter should still be regarded as scientists, and even the statements of the latter shouldn't be considered unscientific generally. Besides, Kuhn came up with the Kuhn cycle to describe how science develops. There is always background knowledge held at a specific time, and it can be shared as common beliefs by the scientific community. In periods of normal science, these

common beliefs are encoded in a paradigm. Scientists attempt to increase common beliefs during these periods. Once an anomaly emerges, a radical change of beliefs can occur, which will lead to a scientific revolution.

Normal science is research firmly based upon scientific achievements which some scientific community acknowledges as the foundation of its further practice during a specific period. Such achievements are called paradigms by Kuhn. It is the system of beliefs as well as the model to solve problems. In the beginning, different interpretations of some particular facts are proposed by different researchers, forming different achievements. Gradually, one of them will dominate the others, then attract a great many advocates until the disagreement disappears. Finally, a paradigm is born. Research during the stage of normal science is a mopping-up activity, i.e. extending the knowledge of facts which paradigm displays as particularly revealing, increasing the match between such facts and paradigm's predictions, and resolving residual ambiguities to further clarify the paradigm itself.

Though an accepted paradigm is more successful than its competitors, it isn't completely successful. It's mostly limited in scope and precision, thus no more than a promise of success. Though the arise of anomalies are usually ignored in periods of normal science, it'll be aware of sooner or later, which is the recognition that nature contradicts the paradigm-induced expectations of normal science. After that, the area where anomalies emerge will be explored more deeply, leading to a further understanding. Then the paradigm will be adjusted in a way that what used to be anomalous becomes the expected, and that's how it changes.

But when a puzzle of normal science fails to be solved persistently, a new theory will usually be brought about. By doing this, scientists may realize that a new theoretical framework is needed. Such a puzzle will become a crisis, and the emergence of new theories and the change of paradigms will lead to a scientific revolution. Such a process isn't cumulative, but rather radical.

However, Kuhn's method of normal science and paradigm still encounters its own problem, which is incommensurability, i.e. failure to propose a criterion to determine which paradigm dominates others. For example, this can occur when two paradigms are logically compatible, and the new one won't accept different predictions from the old one. Each group uses its own paradigm to argue, but none of them can succeed in persuading others, thus leading to a circularity in the debate. And the new paradigm may destroy previous beliefs about nature, which makes it practically difficult to promote the new one.

The demarcation between science and pseudo-science given by Kuhn's method is more realistic. According to it, normal science is stable, because all scientists agree on a paradigm. Therefore, social consensus is the basis for the distinction between science and pseudo-science. Based on this claim, there is no special feature which we can use to tell science from other forms of knowledge and practice. We can even conclude that the high status of science in our society nowadays is unwarranted and potentially dangerous.

Lakatos' Research Programmes

What Lakatos presented focuses on resolving the incommensurability suffered by Kuhn's normal science and paradigm, which involves incommensurable theories by which no common measure is shared. In his view, not all parts of science are equivalent. Some assumptions are more fundamental than others, which constitute the defining feature of science. When apparent failure emerges, such assumptions shouldn't be doubted. Instead, one should blame other components of a theory. Science should be regarded as a programmatic development of some basic principles.

Like Kuhn's view, Lakatos agreed on the comment to inductivism. And he made theories prior to facts. He also emphasized the practice of the scientific community within a historical tradition, but rather than paradigm, he referred to what he called scientific research programmes. In this way, Lakatos objected to Kuhn's incommensurability thesis, and claimed that there is a non-relativistic method to compare different traditions of research.

Research programmes is the vital concept given by Lakatos. It refers to a group of core assumptions, which one won't critique, with a set of methodological rules. It proposes a framework within which scientific practice takes place during a specific period in history.

Research programmes consist of two main components: the hard core and the protective belt. The hard core means the set of fundamental principles of a research programme, which takes the form of some basic hypotheses which the programme develops from. For instance, the three laws of motion are the hard core of Newtonian physics. And the protective belt is the set of assumptions about initial conditions and theories presupposed in the observations. It plays a role in keeping the hard core from falsification. Specifically, any contradiction between the programme and the observational facts ought to be ascribed to the additional hypotheses supplementing the hard core.

An important aspect of research programmes is the heuristic, i.e. the methodological rules adopted to aid discovery and invention. There are two types of heuristic, one is negative heuristic, while the other is positive heuristic. The former implies that if a scientist modifies the hard core, he will opt for another research programme. And the latter gives guidance on how the hard core should be supplemented by additional hypotheses and how the protective belt should be modified to generate explanations and predictions. When departing from the hard core, scientists are involved in another research programme, and that is what Lakatos claims to entail progress in science. According to his thesis, transition from a degenerating to a progressive programme is the manifestation of a scientific revolution.

The shortcoming of Lakatos' thesis is that his methodology should instruct the work of historians of science, but not that of scientists. Thus, his methodology cannot be regarded as prescriptive though his account is descriptive.

The demarcation between science and pseudo-science based on Lakatos' view is whether the research programme has predictive power and coherence or not. Predictive power means that a successful must lead to novel predictions, and coherence means that it must be able to guide future search. Take Marxism as an example. Since it fails to own enough predictive power, it cannot be

demarcated as science.

Feyerabend's Anarchism

Unlike any previous method, Feyerabend presented an extremely radical account of science, i.e. epistemological anarchism. In his view, the concept of scientific method doesn't even exist, thus there is no rule, and anything goes. Besides, science doesn't possess features that are said to make it dominate other forms of knowledge.

Feyerabend claimed that Galileo succeeded in persuading his opponents just because of his excellent rhetoric, and he regarded it as a typical scientific practice. In terms of his opinions, scientists proceed by pure intuitions which cannot be either induced by rules or rationalized. Therefore, they should feel free to create their theories and various ideas ought to be welcomed. In addition, they may use propaganda strategies to advertise their own ideas, which isn't based on pure rationality.

There is no fixed method that scientists must follow in their practice in the history of science. Instead, there are a plurality of methods that have been adopted in different cases throughout history. Feyerabend explained this phenomenon as richness that rules would constrain creativity and intuitions, thus shouldn't be prescribed to scientists.

When talking about observations, Feyerabend took an even more radical stance. He believes that we always interpret the outcomes of observations and experiments against the background of a theory. What's more, he claimed that they are completely theoretical. Moreover, Feyerabend thought that there is no rational basis for theory change and choice, bringing the incommensurability thesis to its extreme.

As is pointed out by Feyerabend, the separation of science and pseudo-science is artificial and detrimental to the advancement of knowledge. One must adopt all ideas, all methods rather than a small selection of them if he hopes to understand nature as well as master physical surroundings.

As for me, I prefer Lakatos' view, since inductivism, falsificationism and Kuhn's view all have their own shortcomings, which are fatal to themselves, while Feyerabend's view is too aggressive and abstract, which I think isn't acceptable up to now. Here I'll take the long-lasting battle between symbolism and connectionism in the field of artificial intelligence as an instance.

Symbolism is an approach that claims intelligence emerges from the manipulation of symbols through explicitly defined rules, which assumes that reasoning, problem-solving, and understanding can be represented within a formal system of symbols and logic. Allen Newell and Herbert Simon, the representative figures of the methodology, proposed the physical symbol system hypothesis which claims that a physical symbol system is both necessary and sufficient for general intelligence. In other words, it's adequate to replicate intelligence through the manipulation of symbols within a formal framework.

The advantages of symbolism include transparency, general applicability and predictability. Transparency means that models of symbolism are interpretable, for all knowledge and reasoning steps are explicitly encoded. General applicability means that the symbolic approach can theoretically address any domain where knowledge can be represented formally. And predictability ensures the controllability of symbolism systems, making them suitable for domains requiring high reliability.

The weaknesses of symbolism are knowledge bottleneck, poor adaptability and limited scalability. Symbolism systems require extensive manual input of knowledge and rules, making it time-consuming to build and maintain them. Furthermore, they are hard to update from new data or adapt to unexpected changes without manual intervention. And as the complexity of a domain increases, the number of required rules can become unacceptable.

Though not as popular as in the past, symbolism still plays a vital role in many areas. When it comes to explainable AI, symbolism still dominates connectionism. Moreover, combinations of symbolism and other approaches are still prospective, such as knowledge graphs and robotics.

Another approach, connectionism, is the study of human cognition that utilizes mathematical models, known as connectionist networks or artificial neural networks.[1] The central connectionist principle is that mental phenomena can be described by interconnected networks of simple and often uniform units. The form of the connections and the units can vary from model to model. For example, units in the network could represent neurons and the connections could represent synapses, as in the human brain. This principle has been seen as an alternative to GOFAI and the classical theories of mind based on symbolic computation, but the extent to which the two approaches are compatible has been the subject of much debate since their inception.[2]

There have been many times of wave for connectionism. The current one has been marked by advances in deep learning, which have made possible the creation of large language models. The success of deep-learning networks in the past decade has greatly increased the popularity of this approach, but the complexity and scale of such networks has brought about increased interpretability problems.[2]

The advantages of connectionism include the ability to learn automatically and handle complexity and ambiguity, high robustness and fault tolerance, and high adaptability. Its disadvantages include lack of interpretability, high computational costs and data requirements, limited reasoning ability, and training instability, making it hard to eliminate symbolism. Nowadays, the two methodologies tend to combine with each other, sparing no efforts to make full use of the advantages of each of them to solve every complicated problem.

Now we demarcate the two methodologies with different methods. By inductivism, we can conclude that they are science, since both have been observed and tested under a wide range of circumstances. We cannot claim that both two methodologies are science simultaneously through falsificationism, for they have given different accounts for artificial intelligence, but meanwhile we cannot determine which is pseudo-science, since neither of them succeeds in eliminating the

other. From Kuhn's view, they can be described as different paradigms and are both accepted by the scientific community as social consensus. Therefore, they both can be called science. They can also be regarded as different research programmes in terms of Lakatos' standpoints, for each of them is predictive and coherent, thus both can be admitted as science. As for Feyerabend, we needn't talk about such a problem which is criticized by him.

References

[1]   https://iep.utm.edu/connectionism-cognition/

[2]   Buckner, Cameron and James Garson, "Connectionism", *The Stanford Encyclopedia of Philosophy* (Spring 2025 Edition), Edward N. Zalta & Uri Nodelman (eds.), URL = <https://plato.stanford.edu/archives/spr2025/entries/connectionism/>.