Popper, Kuhn and How do we get Laws and Theories in Science?

Part-2

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Classification, Analysis & Generalisation as processes leading to Pattern-seeking en-route to Scientific Laws:

As mentioned in the earlier article, human beings are pattern-seeking animals, give us three dots and an appropriately placed curve, and we promptly see a smiling face :-)! From the time we are born, we are constantly observing the world around us and trying to make sense of it. We recognise different categories, we refine these categories, we look for similarities and classify things – both living and non-living. And as we grow older, we just keep on improving these skills and get better at making sense of the world and predicting what is going to happen next.

What science has done is to take these inclinations and fine-tune these practices and apply them with great rigour to obtain better predictions and more control over various processes. Science also requires that all observations be meticulously recorded and reported. This gives rise to the uniqueness of all results being replicable – if a particular experiment is carried out and recorded, anyone else following the instructions for conducting the same experiments will get exactly the same results; and hence the interpretations and conclusions are also transparent.

Classification is one of the most facile of our accomplishments. We are constantly dividing people and things into groups. When we are very young itself, we are able to divide people as family members and others (less familiar people). When we play 'chidiya ud' as children, all things that fly are accepted – butterflies, flies and aeroplanes too. But this game itself shows a mastery over classifying things according to one character – whether they fly or not. And this is the hallmark of classification – that different characters or traits are chosen to categorise things and the choice of the character used to divide things into groups decides the nature of the classification.

Analysis is also a fairly basic skill wherein we try to understand the whole by looking at and trying to understand the parts. For example, if we are trying to plan a garden in a particular place, we will look at factors like the slope of the land there, the type of soil, the amount of sunlight and water available to figure out what plants would do best in that site. In most cases, the nature of most problems we face are so complicated that we do not make the mistake of confronting the whole, but rather, look at its various components in order to crack the problem.

Generalisation is a trap we fall into often, rather, hasty generalisations often lead us to wrong conclusions. For example, during the days when terrorism was wide-spread in Punjab, a few attacks were carried out by militants on Bullets (a brand of motorcycles fairly popular in India). This led the police to stopping and questioning all people traveling on Bullets. What do you think led to this hugely inefficient decision?

When classification, analysis and generalisation is used in Science, the method is the same, but with more checks and balances in place. Let us look at some examples of classification, analysis and generalisation from the discipline of Science before going on to understand how this leads ultimately to the formulation of laws.

Take for example, the manner of classification of elements. At the most basic level, elements can be classified on the basis of whether they generally tend to lose or gain electrons during chemical reactions. These are respectively metals and non-metals – in lower classes, we generally mention only physical properties as the basis of this classification. Hence, the most fundamental basis that has been selected for the classification of elements is how they react. We could have classified elements on the basis of whether they are solids, liquids or gases too – but this would not have led to any further elucidation of their properties and hence would not have been meaningful.

Analysis is widely used because most natural systems are highly complex and difficult to comprehend as a whole. For example, Galileo and Newton showed us how to understand the motion of an object like a cannon-ball which moves in a parabolic trajectory. We can do this by the process of analysis wherein we break up the motion of the cannon-ball into its vertical and horizontal components. Then, and only then, is it easy to see that the cannon-ball's horizontal motion is happening at a constant velocity while the vertical component is that of accelerated motion. This is a fairly simple example of the method of analysis being used, but you can try and think of other examples too.

Generalisation too is a commonly used method in Science. All the laws that one has learnt is generally the result of a generalisation from a series of observations. For example, Mendel's laws of inheritance were arrived at as a result of studying the variations in different traits in pea plants over many generations. See if you can find Mendel's original data which led him to arrive at the law of dominance. In this method, we look at a phenomenon many times and under varying conditions and try to find the variables that affect the phenomenon and what is the nature of this relationship. To take another example, when Robert Boyle was studying the effect of pressure on the volume of a gas, he kept the sample of gas at a constant temperature, changed the pressure and recorded its effect on the volume. After carrying out this experiment repeatedly and looking at how the volume of the gas changed when the pressure was increased or decreased; and further, repeating this experiment with different gases and at different temperatures too, he came to generalise that when the pressure was increased, the volume decreased and vice versa. That is, Boyle's law states that the volume of a gas kept at constant temperature is inversely proportional to it pressure.

Hence, using the processes of classification, analysis and generalisation, we are able to discern the patterns behind seemingly chaotic behaviours. These patterns are then normally put forth in the form of different laws. Basically, the laws reveal that there is method and order to the different phenomena that we see around us and that it is possible to make sense of the universe and make confident predictions.

So we have laws, where does the theory come from?:

Even though you might feel after reading the earlier section that understanding nature is a straight-forward process of making observations and discerning the patterns behind each phenomenon, Science is much more than arriving at laws. The main role of Science is to provide explanations for these patterns. And these explanations are called hypotheses or theories. How does a scientist go from a law to a theory about why that particular law applies? How does one propose a particular theory?

According to the earlier ideas about the nature of Science, the theory followed directly from the data or observations, that is, there was a simple and direct relationship between the observations and the theory. But Popper said that the role of Science was to detect the underlying reality behind our observations, that is, to provide explanations for why we see what we see. According to him, given a set of observations, one could think of many explanations, that is, one could come up with more than one theory that explained why we saw only what was being observed and not some other phenomenon. Further, these different theories would make novel predictions that were about events that have not yet been observed and we could then choose between the rival theories on the basis of which theory was able to explain a greater number of phenomena and made the best and more novel predictions

Let us understand this with an example. Both Newton's theory of gravity and Einstein's theory purport to give an explanation for why planets go around the Sun (amongst other things). Newton proposes a force between two bodies that depends on their masses and the distance between them. Note that force is a hypothesis, we can never observe a force, we can only observe the effects of a force. So, according to Newton, the force of gravity causes the earth and other planets to go around the Sun. According to Einstein's theory, massive bodies cause the distortion of the space around them, that is, space is curved around all bodies (having mass) and the greater the mass, the more the curvature of space around them. This causes the earth to go around the Sun instead of going off at a tangent.

You will observe that both theories give different explanations for the earth (and other planets) going around the Sun, that is, the same observations have given rise to two different theories. So how does one choose between them? We then have to look at the number of phenomena that are explained by these rival theories and what novel predictions are made by them. As seen earlier, Einstein's theory was able to predict that light would bend because of massive bodies like the Sun because space was curved due to the mass of the Sun. And hence, today we accept Einstein's theory to be a better and closer explanation of the data than Newton's theory of gravitation.

But this brings us to the question of how we arrive at any theory. Once again, according to Popper, theories have a creative aspect to them – they are the creations of an individual human mind. This seems to indicate that different people would come up with different theories! Would all these theories be equally good?

Let us look at some general guidelines that help us to work out a good theory. Any theory involves some assumptions, and an old working rule attributed to Occam (called Occam's razor) says that the theory that uses the minimum and most simple assumptions is the best. For example, the kinetic theory of gases that gives an explanation for the temperature, pressure and volume of a gas assumes that the gas is made up of particles which are hard and elastic and have negligible volume, and that they are in constant motion. These assumptions are used to arrive at a model for the behaviour of gases.

Another strategy used by scientists is the process of idealisation. For example, when Galileo was studying motion, once he figured out that an unseen force causes moving objects to ultimately come to a stop, he was able to simplify things and imagine what would happen in the absence of friction and arrive at his three laws that describe motion (these three laws are subsumed into Newton's first law of motion). Likewise, if we want to describe the motion of a bus going from Bhopal to Indore, we would soon come to the realisation that what matters in this particular instance is the motion of the bus as a whole. The motion of the steering wheel, windshield wipers or the tyres and axle are of no consequence. And so it is possible to think of the bus as a 'point mass' that is going from Bhopal to Indore. Thus, the idea of a 'point mass' is an idealisation.

Another technique that is used to figure out what the factors affecting a particular phenomenon are is the use of a control. That is, the phenomenon is studied in two cases, each exactly the same, except for the one factor being studied. This technique is widely used in Biology where it is difficult to understand the ramifications of different factors and how they impinge upon each other. For example, if we want to study the effect of light on the germination of seeds, we could place 'chana' in two petri-dishes on wetted cotton and keep one petri-dish on the window-sill and one inside a box or inside a dark cupboard and observe them over the next few days (making sure that the contents of both petri-dishes are not allowed to get dry).

We are all familiar with the use of experiments to study different phenomena in Science, and hence we are not going into it in detail over here, but another method used in Science is that of thought experiments. A thought experiment is an experiment which can't be practically carried out, but on the basis of earlier experiments, a scientist thinks out implications in his or her mind and thus is able to fine-tune ideas and theories. Try and find out about the famous thought experiments attributed to Galileo and Einstein.

Lastly, a method that has come into use in the 20th century thanks to the advances in statistics and computation is to look at biological phenomena like animal behaviour in the wild and using statistical methods to tease out confounding variables and figure out what the underlying causes of various behaviours are. An example is the study of altruistic behaviour among social animals. Earlier, these studies were done using captive monkeys, but these would have been collected at different times and places, and so the group was not based on kinship. But now the study of groups in the wild has shown that altruistic behaviour is based on kinship and is built over many generations so that monkeys will prefer to support another that they are related to rather than side with a more powerful individual (which was what was observed with captive monkeys). Similarly, statistical methods are used to study populations and their relation to the various environmental components in their habitats.

Conclusion:

In this article, I have tried to address some issues related to the nature and method of Science. But debates continue, Kuhn's ideas opened up the discipline of Science to the discipline of Social Science, and further the so-called objectivity of scientific claims have been questioned by feminists, and Science has also been charged with being racist and destroying the environment. What are these issues, how valid are these points being raised? And something that has not been taken up yet, what is the relation between science and technology (if there is a relation at all)? These are all fertile fields for exploration in future articles!! And not necessarily by me, but questions and comments are welcome as always.