Research Methodology

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Lecture - 07
Logical Reasoning: Inductive Logic

Well, today we will start with Logical Reasoning. It is obvious that all our activities are conducted using some kind of logical reasoning. But if one is untrained in the act of doing proper logic, then one can make incorrect application of logic and so, in that case, we will arrive at wrong conclusions. Our actions will be wrong and all that can happen. And this is very important in case of scientific activity because any incorrect inference, any incorrect deduction, may lead to embarrassment and may lead to papers being rejected, and so on and so forth.

So, even though much of the things that I will be talking about may appear to be following from common sense; but still this has to be learned. Because there are enough evidence that many people make mistakes with making proper logical inferences. Logic is essentially the systematisation of reasoning, and reasoning is something that we have to do all the time. Therefore, we have to apply systematic method of reasoning.

Logicians since antiquity have worried about this problem: how to systematize our reasoning? How to distinguish between faulty logic and correct logic? How to make correct inferences based on certain premises? And they have come to the conclusion that there are essentially two distinct types of logical structures. One is called inductive logic and the other is called deductive logic.

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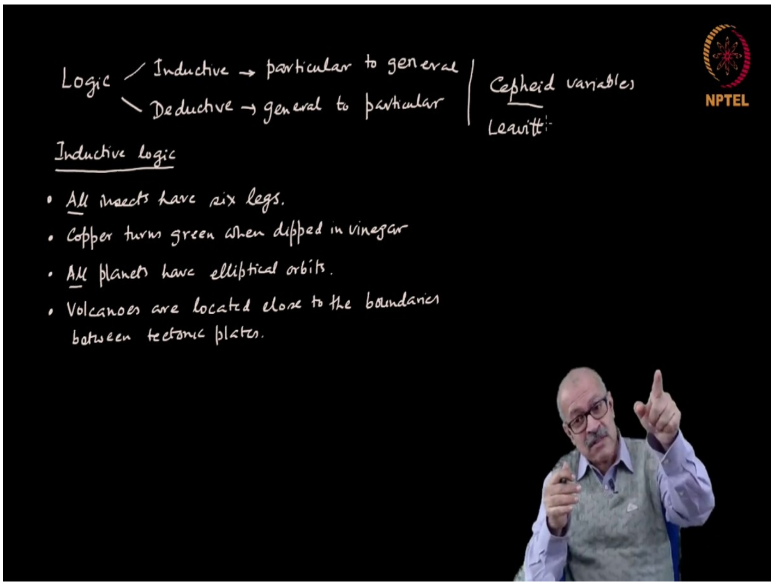

So, logic is two types; inductive and deductive. If we see our day to day activities, it is easy to see that we do apply the inductive logic and deductive logic every day, without realizing that we are applying this. For example, suppose you see cloud when you are going out of the house and you take an umbrella along. This is a very common-place activity. Right? But what was the logical reasoning that went in your head, in your mind?

It was that since your birth, you have seen repeatedly that before it rains, the sky becomes cloudy, and so your mind has made a logical connection that if the sky is cloudy, then it may rain. This kind of going from the particular every day events: I see cloud and then rain; cloud and then rain; these particular events, everyday events, and using the repeated occurrence of the particular event, we arrive at the general conclusion that if there is cloud in the sky, it may rain. Essentially this is an example of inductive logic, where we go from particular to general. We go from particular to general and that is the structure of inductive logic.

Now, on a particular day, if you do see cloud in the sky, then you infer that today it may rain. Since you have already made an inductive argument in your head that—if it is cloudy, it may rain—as a general premise. Then, on that particular day, when you see it cloudy, you infer that it may rain and take the umbrella along. So, that is an example of deductive reasoning, where it is from the general to the particular.

And all our logical reasoning is based on these two types of logic. Today, let us start with inductive logic and progress step by step to understand these logical structures.

Let us start with inductive logic. As I have just said, it is the act of going from the particular to the general. It is true that without forming inductive inferences, humankind not cannot even take a single step. Everything that we do, behind that there are some kind of inductive inferences. For example, people saw a seed germinating into a plant, another seed germinating into a plant, third seed germinating into a plant and then, they made a general conclusion that seeds germinate into plants. And so, they inferred that wherever I want the plant to be, let us put the seed there. That reasoning was the beginning of agriculture.

So, it is easy to see that inductive logic is essentially ingrained in all our reasoning. But in modern science, Francis Bacon underscored the importance of inductive logic in building our idea about nature. His logic was that, in order to build the idea about nature, workings of nature, laws of nature, what we need to do is to collect data, information, on a large scale about everything. Keep on observing. And then, put the data together and using inductive logic, you try to extract the general principles, the laws of nature.

The way is by repeated observation. Rain is preceded by a cloudy sky. By repeated observation of that, we came to the conclusion that if it is cloudy, then it may rain. That is, from particular to general. His prescription was that. That way, you collect a large number of particular observations and from that try to extract the general principles and that would be, for you, the laws of nature.

So, his prescription was to apply inductive logic on a large scale and science was very successful in doing that. Most of the sciences in the 17th–18th century developed following this prescription. That is why in the 19th century, much of the sciences were called ‘inductive sciences’. You will see the reference to inductive sciences in many places; the reason is that science was developing by applying the inductive logic.

And that is what allowed us to do many classifications. Classifications means, for example, classification of animals into reptiles into mammals, insects and vertebrates, invertebrates; classification of chemicals into acids, alkaline substances, aromatics, sugars. So, all these classifications, putting them into bins, that could be possible only when we could extract some general properties from many particular things, abstracting the general properties.

That way, we could classify the natural world by using inductive logic and that helped the development of natural science in many ways. Let us then dissect the actual act of applying inductive logic. What are we actually doing? Let me write some possible inductive inferences.

All insects have six legs. That is an inductive inference. Notice that we have not really counted the legs of all possible insects. We have only counted the legs of a *sample* of insect population and in every case, we have found that the sample that we have collected and counted, had six legs. So, we have generalized the premise and come to the general conclusion that *all* insects have six legs that is the typical application of inductive logic.

A copper turns green when dipped in, say, vinegar. Somebody may have dropped a piece of copper in vinegar, it turned green. Then another person did the same, third person did the same and finally, by generalizing these particular observations, we come to the conclusion that copper in general turns green when dipped in vinegar. That does not mean we have dipped all possible pieces of copper in all possible solutions of vinegar. No, we have done it a few times and then, abstracted the general property that we observed.

All planets have elliptical orbits. When Kepler studied the planetary orbits, he did it only with five planets; Mercury, Venus, Mars, Jupiter, Saturn. These were the five planets known at that time. And he found by his calculations that in all the cases, the planets have elliptical orbits. So, people generalized the idea to say that all possible planets have elliptical orbits. That is what Newton worked on. He was asking why should planetary orbits be elliptical, with the centre of the force at one focus. So, this was actually tested in a small number of cases. But we generalized, and that is what enabled us to extract a whole law of nature, the law of gravitation. It is so very important.

Let us take one example from earth science. Volcanoes are located close to plate boundaries, the boundaries between tectonic plates. This is also obtained by actually observing the location of specific volcanoes, particular volcanoes and drawing the plate boundaries. People found that, yes, they are located very close to the plate boundaries.

They made a general conclusion out of that: in general, volcanoes are located close to the plate boundaries.

So, in all these cases, you will notice that we have actually observed a small number of cases and yet, we have inferred a general law out of that. Because of that, some philosophers have raised the point: can we really trust inductive inferences? Is it really trustworthy?

Why? The reason is that, they argued that, it is possible that at some point of time, we find a particular insect with not six legs, but five or seven or something. Then? Then, the whole inference that all insects have six legs will fall apart. So, their argument was that even one counter example will make an inference go wrong.

Let me give an example. In general, human hearts are located to the left hand side of the chest and if you collect a 1000 individual humans and if you find where the heart is located, most probably you will find that it is located to the left of the chest.

Yet, it is true that such humans do exist who have the heart in the right side of the chest and the lungs on the left side. Such cases do exist even though the general case, the heart being in the left side of the chest, that is true about 99.99 percent of the cases.

But such very rare cases do exist. Therefore, if you apply the same method of arguing and if you proceed by collecting, say, 10,000 humans, test them, and then by generalizing, conclude that all humans have heart located in the left hand side, then obviously, that would be wrong. So, the philosophers pointed out that, the inductive logic is not trustworthy. And some went to the extent of saying that let us forget about inductive logic altogether. Let us not use inductive logic at all.

Unfortunately, science cannot progress without using inductive logic. In many cases that is the only way, the only thing in hand. I will give you some examples.

Field biologists have noticed that there are ecological spaces. For example, the African savannah, a savannah means the vast grassland, in which zebra, wildebeest, Tomson’s gazelles and many other grazing animals live together and they share the same kind of space.

The field biologist looked for what are the differences. Difference means difference between the niche; what each animal eats, what each animal prefers, what are the typical predators of each animal and what are the typical diseases of each animal and all that are put together is the niche. They found that there is always some difference in the niche occupied by each species and from there, the general conclusion emerged that each species occupies a single niche.

Now, this definitely was not obtained by studying all possible species. This was obtained by studying a few species living together. But then, scientists generalized that, and made a general conclusion that each species occupies a single niche. Following that, whenever a field biologist goes to a particular area and studies, if he or she finds that many similar species are occupying the same area, same location, living in the in side by side in the same area, they always look for the difference in the niche. And they always find, which means that that inductive conclusion also gave a direction of research.

That research was successful research and without that inductive conclusion, we would be rather clueless as to how different animals leave in the same space, share the same space. But now, we understand that even though they appear to be living in the same space, there are always some difference in the niche.

In the same way, let us come to an example from astronomy. How do we know the distance to the stars? That is one of the elementary informations an astronomer has to collect: how far is that particular star.

In general, distances are measured by the method of parallax. Parallax means, our two eyes have a certain distance between them, due to which if you hold something in front, then the line joining that eye to that object and the line joining this eye to that object are different, and there is angle between them. And it can be easily gauged, if you open one eye and close the other and then open this eye and close the other, you will find that the position of the finger has moved in on the background of the background objects.

So, if you take two pictures from these two locations by seeing how the background has changed, you can figure out the parallax angle and from there, you can find out the distance. This was the method used to find out distances to relatively farther objects; for example, the moon. But the distance between the two eyes are very small so that the that parallax angle would be too small to measure.

So, in case of finding the distance to the moon, we would place the two eyes at two distant places. For example, one is Calcutta, the another in Delhi. Then, we take two photographs and by matching the background objects behind the moon, you can find out the parallax angle and from there, you can find out the distance to the moon.

And in the same way, the distance to all the planets have been measured. But the distance to the nearest stars cannot also be measured in the same way. Because the stars in general are so far that even the diameter of the earth is insufficient to subtend a reasonable parallax angle. So, what do we do then? Then, we took take a picture in one season, say summer, another when the earth has gone around to the other end of its orbit around the sun and then, take another picture.

Thus, the distance between the two eyes becomes large enough because it becomes the diameter of the earth’s orbit around the sun, and then we can measure the distance. And that way the distances to the nearby stars were measured. It was found that even that is insufficient to measure the distances to the farther stars. So, what do we do then?

After all, we cannot have two eyes with the distance between them more than the distance of the diameter of the earth’s orbit. You cannot have any further distance. Then, astronomy came to a standstill, because we cannot measure any further distance.

In that situation, it was noticed that there are some stars which pulsate regularly in a very regular fashion. The period is fixed. These are called Cepheid variable stars. Let me write the Cepheid variable stars. There were some Cepheid variables within the range to which we could measure the distance using parallax. One scientist named Henrietta Leavitt specifically focused on this issue. She measured the distances to these stars which can be measured using parallax and she studied the character of their pulsation.

From the distance and from the apparent luminosity, you can find the absolute luminosity; that means, how much light its emitting. She plotted a graph linking the period of oscillation and the absolute luminosity and she found a straight line like graph. If it is straight line; that means, that there is a direct linear relationship between the period of oscillation and absolute luminosity.

That particular result was based on some 10 starts. After she published this result, people realized that, if we take that as a general character of all Cepheid variables—that their absolute luminosity and the period of oscillation are related by a straight line relationship—then it gives us a way of measuring further distances. How? Because, however far a star may be, the periodicity can be easily measured because that is visible. So, the periodicity can be measured. From that relationship, we can find out the absolute luminosity. We can visibly measure the apparent luminosity, and from there, we can find the distance.

So, that actually opened a new door to measure the farther stars. When Edwin Hubble started working in the Mount Wilson observatory, he directed his attention to one of those fluffy objects that was there in this sky, the Andromeda, at the time it was called a nebula, and he could discern individual stars in that nebula. So, he realized that it is not a nebula. It is a galaxy.

Interestingly, he located a couple of Cepheid variables in that Andromeda galaxy. The moment you can locate a Cepheid variable, you can of course measure the distance. So he could measure the distance. He could measure the distance not only to that particular star. Because the star was a part of a galaxy, and therefore, it was a measurement of the distance to that galaxy. That is what first established that the Andromeda is not inside our galaxy; it is far away from our galaxy and so on and so forth.

Not only that, then he established a relationship between their recession velocity; the velocity with which they recede and their distance, and that established what is called the Hubble’s law, and the whole of cosmology today is based on that. Now, let us dissect the line of logic that was going in the whole activity.

The line of logic was that Henrietta Leavitt observed a few particular Cepheid variable stars and obtained a some kind of relationship. For those particular stars, she found a law. The law is that linear relationship between the absolute luminosity and the periodicity of the oscillation. Then, scientists applied inductive logic to say that this is a law applicable to all Cepheid variables. The moment they had that, they had a new weapon in their hands to measure the distances to farther stars. The whole of astronomy and cosmology rest on that today. It rests on an inductively obtained inference.

So, the point is therefore, science cannot really work without such inductive inferences and we have to go on with inductive inferences. But we always have to keep in mind that particular cautionary word from philosophers that, yes, if we find at some point of time that the inductive inference is wrong, which means that we find a counter example, then that kind of statement cannot be made, then we have to say something else.

I mean we may have to talk in terms of the probability of something happening. Because of this, whenever we obtain a inductive conclusion, there are two types of statements that we make, since scientifically we know that an inductive inference can be, at some point of time, proved wrong.

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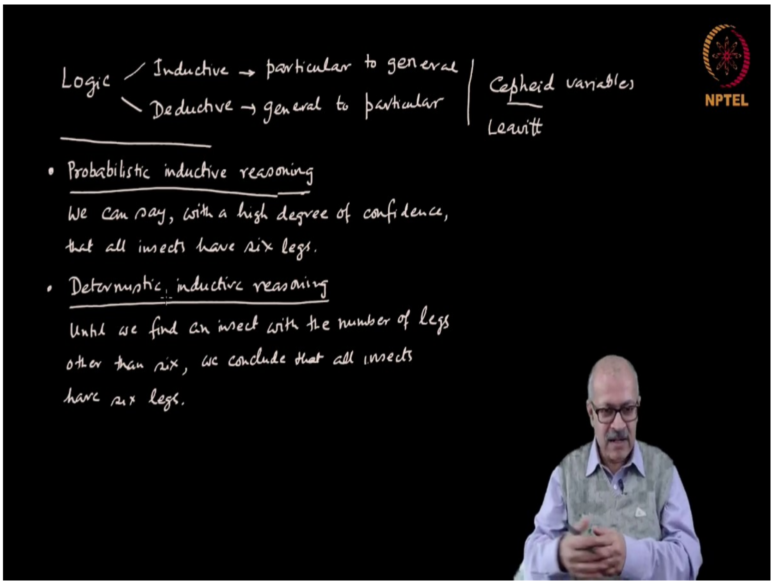

The scientific way of stating an inductive inference is something like this. One is called the probabilistic inductive reasoning. Let us consider the situation where we are talking about insects having six legs. We can say, with a high degree of confidence, that all insects have six legs, because we have only measured a sample and not all possible insects. Therefore, we cannot be certain, and therefore, we only say that we are stating this with a high degree of confidence.

And when we say that, 'with a high degree of confidence', we are actually stating something related to the probability. That means, with a very high probability, all insects will have six legs. This is to be on a safe side. You are not stating that all insects have six legs; but we are saying with a high degree of confidence that all insects have six legs. Therefore, there would be a question of how do define the degree of confidence; how to define the probability that this will be true and all that. I will come to that in a later part of this course.

The other way of saying this is called deterministic inductive reasoning. In deterministic inductive reasoning, we say that 'until we find an insect with number of legs other than six, we conclude that all insects all insects have six legs'.

So, you see, here in this case, we are accounting for the possibility of a counter example being found at a later point of time. But until such counter example is found, we can say with confidence that all insects have six legs.

So, there are two possible ways of making the statement: one is the probabilistic way, another is a deterministic way; both are scientifically correct.

But the point is that without making inductive reasoning, we cannot go ahead in science. We cannot really take any step in science; the reason will be clear a minute later, when you see that all deductive reasoning is based on some prior inductive premise, something that has been arrived at prior to applying the deductive reasoning, using inductive reasoning. So, therefore, inductive reasoning is essential in carrying out the act of science.

And so my advice would be, please do not give too much importance to those philosophers who say that do not use inductive inference because you can never be sure that inductive inference is correct. Science cannot really proceed that way.