Research Methodology

Prof. Soumitro Banerjee
Department of Physical Sciences
Indian Institute of Science Education and Research, Kolkata

Lecture - 25
Falsifiability and Reproducibility, Part 01

While we are doing the ‘philosophy of science’ part of the course, we talked about a few things, which we now have to apply in the actual act of doing science. For example, we said that earlier the way of thinking was subjective and post-Renaissance, the way of thinking of science has become objective.

Then we have to think how to apply that to the actual act of doing science, designing experiments and things like that, where we deliberately eliminate all possibilities of my own subjective belief and judgement influencing the experimental result. So, we need to eliminate those possibilities of subjectivity because the whole thing is, in a very strong way, objective.

We have also learnt that, in the realm of philosophy, there are major two schools of philosophy: Idealism and Materialism, and we have learnt that we science actually roots itself on materialism. What does it imply on the actual act of doing science?

We have learnt that the things that scientists do are essentially formulating scientific questions and trying to answer those questions. In answering those questions, we formulate hypotheses, we formulate postulates, and so and so forth. But, while doing so, one hard requirement, then, would be that, we should not take recourse to any idealistic beliefs.

If we are formulating a hypothesis to explain something, for example, ‘how did the Earth come in to being?’ – that kind of a question, a scientific question, then the hypothesis should be based on material processes and phenomena that can actually happen with material entities. We cannot take recourse to ideas like somebody created that, somebody willed that. So, that kind of hypotheses are not entertained in science.

You will see that there are things that we studied in philosophy, but that is ingrained in the process of doing science, the method of doing science, in a very methodical way. We will come to those details later, how we implement those ideas in the actual act of doing science.

We have also learnt about causality and much of science is actually trying to find the courses or something. So, the things that we learnt in the chapter on causality will be again applied to the actual act of doing science.

And then we learnt about Logic. We learnt that there are basically two types of logical structures: one is inductive logic, the other is deductive logic. Inductive logic goes from the particular to the general, and deductive logic goes from the general to the particular. Inductive logic is applied in practically all fields of science.

Even though we know that, if any contrary example is found, then the premise that has been created by inductive argument will be nullified. For example, I said that the whole of astronomy is based on measurement of distances to stars, and beyond the distance that can be measured by parallax, all the measurements are based on the observation of Cepheid variables.

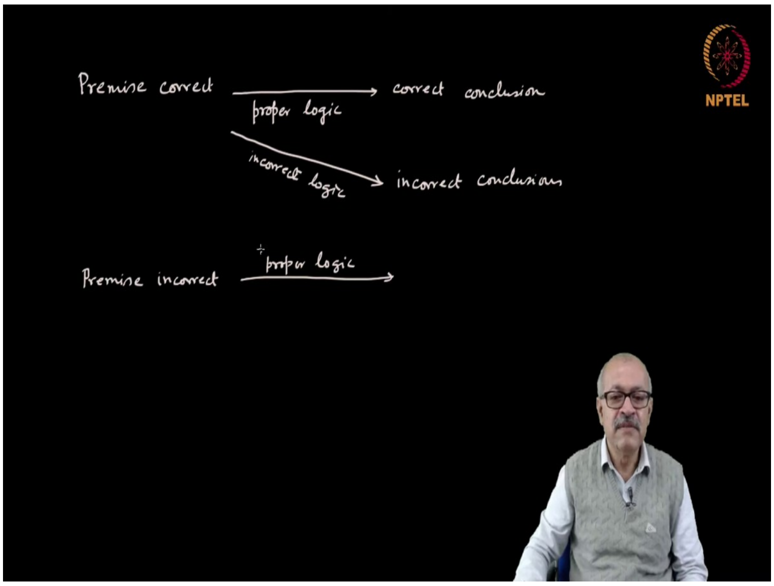
And Henrietta Leavitt showed that, for the Cepheid variables that are within that range of parallax measurement, these Cepheid variables follow a particular linear curve between the absolute luminosity and the period of oscillation. And then scientists said that, fine, in that case let us assume in an inductive way, that all Cepheid variables follow that particular curve.

That means their positions on the period of oscillation versus the absolute luminosity curve (they are also located somewhere on that line), which means that it follows a linear relationship. When they assumed that, they actually were taking recourse to inductive logic. It is clear that, had they not done that, there would be practically no astronomy because we would not be able to measure any stellar distances.

So, it is a necessary thing. But we also know that, if at some point we discover a particular Cepheid variable, that is a single Cepheid variable star, which does not follow that pattern, then the whole inductive premise that has been created, on the basis of which people have applied the deductive premise for particular stars, that will be nullified.

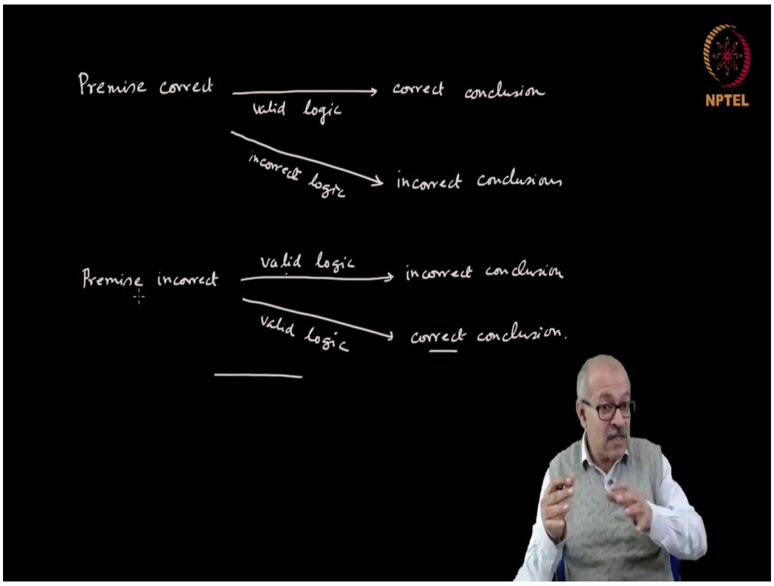
We know that. So, these decisions, therefore, are provisional until a contrary example is found. Science works that way. Most of the ideas that science would develop, then would be provisional, until a contrary example is found. Similarly, in applying a deductive logic, we start from a premise or a number of premises and then we come to a conclusion.

(Refer Slide Time: 06:58)



We have learnt that if the premise is correct, then apply proper deductive logic and you get a conclusion which is a correct conclusion. And, if you apply incorrect logic, then you may arrive at incorrect conclusions. But if you start from a premise which is incorrect then by applying a proper logic (proper means valid logic), you may get a correct conclusion. For an incorrect premise, you will normally get an incorrect conclusion, but we also learnt that using a valid logic, you can also get a correct conclusion. Notice the examples of these, which we have shown.

(Refer Slide Time: 08:32)



So, if the premise is correct and if you use valid logic, you always get a correct conclusion. But, science works by actually formulating questions, problems, and then formulating hypotheses or postulates in order to answer those. These, then, from the premise on the basis of which scientists would build their logical structure.

So, premise would be formed by the hypothesis that one proposes. But, the hypothesis itself is not testable; a postulate itself is not testable. What are testable? Testable are the logical deductions. That means, starting from the hypothesis, starting from the postulate, one would make a logical deduction to arrive at something which is testable.

For example, in case of the Newtonian law of gravitation, Newton postulated that any two bodies attract each other with a force equal to G m1 m2 by R square. And, then he said that, if I assume that, then I can show how the planets would move. People found that the planets do move that way.

It means, ‘if I assume that, then I can show this following valid logic’. So, what forms the initial premise? It is the postulate or the assumption the scientist makes. And then he would apply valid logic to arrive at some conclusion which can be tested, some conclusion like the motion of the planets.

This is how science works. The initial hypothesis can be right or wrong. Both possibilities are there. If the initial hypothesis is right, then if you apply valid logic, you get a valid conclusion, which can be tested. But, if you start from incorrect premise, which means that your initial hypothesis is wrong, then also using valid logic it is possible to arrive at a correct conclusion. We have seen examples of that. Right?

Which means that, if you test the conclusion experimentally, and find that the conclusion to be correct, you cannot infer that the premise was correct. This is a very important logical issue in science that, if you have experimentally validated some conclusion of a hypothesis, that does not immediately imply that the hypothesis is correct, because of this logical issue.

But, if you get a positive result, if an experiment corroborates the predictions of a hypothesis, then our confidence in that hypothesis increases. We can provisionally take that hypothesis, and carry on our research. All that is true. But we have to remember, that does not *prove* the hypothesis is to be correct; that does not *prove* the postulate to be correct.

There is another issue. The issue is that, we have seen through our experiences, that at some time, Newton's theory of gravitation was proposed and it was tested on thousands of different situations involving planetary motions, projectile motions and many things. And in every case, it was successful. That means, the logical consequences of the hypothesis were tested to be correct. So, we said that the initial the premise that Newton started from, i.e., the law of gravitation and the 3 laws of motion, are correct.

But when we looked at the motion of Mercury, we noticed that it does deviate from the one that is predicted by Newton's laws and therefore, we realized that Newton's laws cannot be absolutely correct. It is not correct in every possible situation. There are exist situations where it will prove to be inadequate.

In case of the law of electromagnetism that was established through the experimental work of Ampere, Gauss, Faraday and others, and was finally given a mathematical shape by Maxwell, that was absolutely successful in most situations. But when we tried to apply that in subatomic particles, then we found that it simply does not work.

What lesson do we learn from these? The lesson that we learn is that, this was actually said by Einstein, "No amount of experimentation can ever prove me right; a single experiment can prove me wrong". A single experiment can prove my theory to be wrong; this is a very important thing.

A hundred experiments corroborated Newton's theory, but a single observation showed that there is a problem. A hundred experiments corroborated Maxwell's theory, but a single attempt to apply to subatomic particle showed that it does not work. So, the general lesson that we learn from there is that, you cannot ever prove a theory. You cannot ever prove a hypothesis, because if a hundred experiments prove a hypothesis then also a 101th experiment can disprove it. It can show some lacuna in it, can show some inadequacy in it. Therefore, it cannot be pronounced to be absolutely true.

If that is true, what does science stand on? If you can cannot prove a theory to be true, absolutely correct, then what confidence do we have in science? Science is faced this question, and the philosopher Karl Popper said that, since it is not possible to conclusively prove a theory, then the reverse is true: it is possible to conclusively disprove a theory. It is possible to falsify a theory.

So, a very important conclusion emerges. We have seen here, that a incorrect premise with valid logic can lead to a correct conclusion, which can be tested to be correct. Therefore, that does not imply that the initial premise was correct. At the same time, if the initial premise has been tested by hundreds of experiments, then also in a certain situation it may prove to become inadequate.

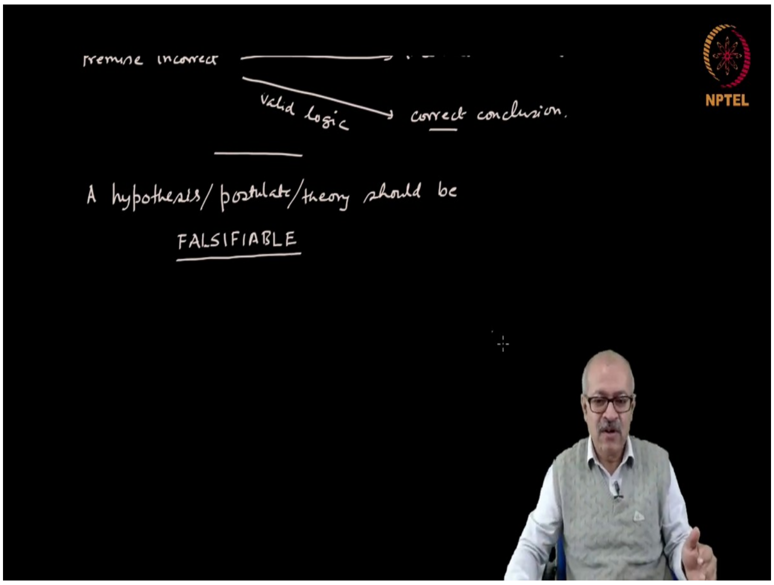
In that case we do not say Newton's law is wrong or untrue. We do not say Maxwell's law is wrong. We say that under certain condition, it becomes invalid, it becomes inadequate. Because of this, the idea that was developed is that, faced a situation, faced a question, a scientist should try to formulate as many hypotheses as possible. Then test the hypotheses, and find out which hypotheses are wrong and eliminate them. That way we will inch towards the truth, the true conclusion about the thing.

As I have already said, we cannot ever reach in the truth because if we reach the truth then there is nothing to be done. Therefore, we progressively go towards the truth, which means our ideas become more and more approximate reflections of reality.

And the way to do that would then be, faced with a question, we should formulate as many hypotheses as possible. And then the hypotheses should be tested and the ones that are wrong should be eliminated. If this program is to work, then there is a hard requirement on any theoretical work.

Theoretical work means proposing a postulate or a hypothesis and working out the logical consequence of the postulate or the hypothesis. In case of any theoretical work a very hard requirement is that the theory, the postulate, the hypothesis, should be falsifiable. This is important.

(Refer Slide Time: 19:36)



Let me write it. A hypothesis or postulate or theory should be falsifiable. What does that mean? It means that, it should be in principle possible to conceive a situation, an outcome of an experiment, so that, if that outcome comes, then the theory is definitely false.

So, *in principle* falsifiable. It is conceivable to have an experiment or observation, which will falsify the theory. If a theory is proposed, a hypothesis is proposed, a postulate is proposed, such that no experiment, no observation can prove it to be false, then, obviously, science would say that that is not a scientifically valid proposition of a theory or a hypothesis or a postulate. Very important.

It does not mean that the one that you propose is false, that you have to propose false theories. No. ‘Falsifiable’ theories, which means that it should be conceivable that certain experimental outcomes would prove that the theory is false.

Let me give an example. Suppose somebody has a disease, say malaria. The doctor hypothesizes that the person has malaria because there are symptoms of fever with shivering, the fever condition comes and goes, and things like that. So, when those conditions are reported to the doctor, he makes the hypothesis that the person has malaria.

And then he says that malaria happens because of a parasite that goes into the blood and it is carried by mosquitoes. So, the person must have been bitten by an infected mosquito and by that means, the parasite must have entered the body. It is a hypothesis. Is this hypothesis falsifiable? Yes.

Because, if you take a bit of blood from that person and examine under the microscope and you do not see any of these parasites, then, obviously the hypothesis is false. There was another part of the hypothesis: that it is carried by mosquitoes. So, if the person is living in a place completely divoid of mosquitoes, there is no mosquito there, and he has not gone out of the place anywhere in the last a month or so, then, obviously he has not been bitten by mosquitoes. If he still has that condition, then the hypothesis is false. Then it is definitely not malaria. It is something else. So, the doctor makes a hypothesis and that hypothesis is falsifiable. It is conceivable to perform a test by which we can declare the hypothesis to be false.

But if somebody says that he has that condition, he is suffering, because he did some sin in the previous birth, will that hypothesis be falsifiable? Can you conceive an experiment or an observation that will prove the hypothesis to be wrong? No. And, that is why science does not even bother about such hypotheses.

So, science would not bother about a hypothesis or a postulate or a theory that is not falsifiable. Very important conclusion whenever any theorist does any theoretical work. Basically all theoretical work comprises either proposing a hypothesis or proposing a postulate or working out the logical consequences of a hypothesis or postulate, which is then tested by experimentalists. That is what a theorist does.

Now, when a theorist works, all the time he or she has to keep in mind that whatever I am doing must be falsifiable. But there are situations where the falsifiability criterion may not be testable right now. For example, the take the case of, say, string theory. The whole theoretical structure is developing to explain certain things that are observed. But we have not been able to perform any test to check the validity of that particular theoretical structure, which means that even though it is falsifiable in principle, we have not been able to devise the experimental apparatus by which we can falsify that. So, we are waiting. Maybe sometime later we will do that. But still, in principle, it is falsifiable.

Similarly, when Einstein proposed his general theory of relativity, a logical consequence of the theory was that there should be gravitational waves. Then, if it were so that there is actually no gravitational waves, then the theory must be wrong. So, that is a falsifiability criterion.

We were not able to produce an apparatus that would detect gravitational waves for over hundred years. But still people kept trying. And finally, only a few years back we have been able to construct the experiment and finally, we have been able to detect gravitational waves.

When it was detected, scientists said that the experiment corroborated the theory and when it is corroborated, it increases our confidence in the theory. But that does not mean we take it as absolute truth. That does not mean we stop testing the theory any further. We keep on testing the theory and whenever any lacuna is observed, that becomes the starting point of another theoretical development. So, any theory should be falsifiable is a very important conclusion of science.