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

**Lecture - 26**
**Falsifiability and Reproducibility, Part 02**

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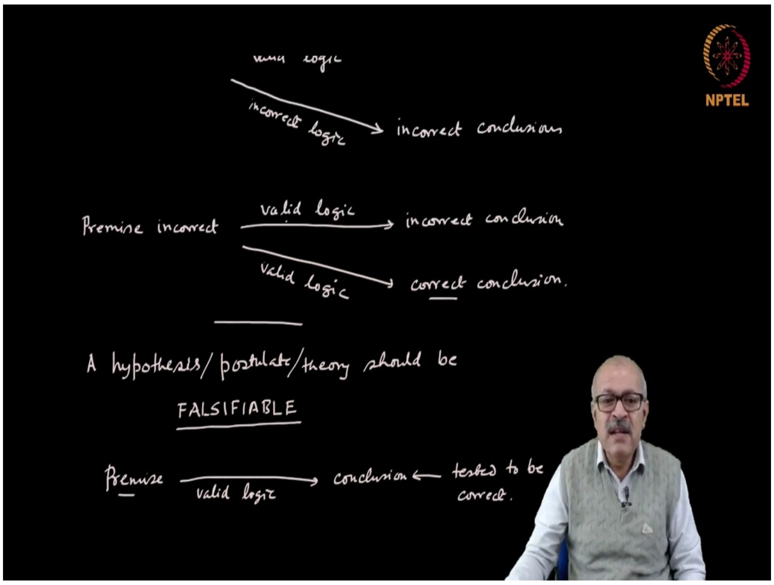


So, the basic idea is that, we can never be sure that a theory is absolutely right. It is not possible to pronounce a theory to be absolutely right. And therefore, science stands on its ability to reject wrong ideas. There are lots of ideas around. Out of that, which are wrong we can definitely pin point that by experiment, by observation. We can pin point that and reject that. And science as progressed so far by proposing various ideas and rejecting the wrong ideas.

So, this is how science has progressed and is still progressing. Because of that, if there is a question, for example, ‘how was the Earth created?’, if you have a question like that, then there can be various possible hypotheses and definitely all the hypotheses will not come out to be correct. The scientific endeavour is to propose as many hypotheses as possible.

Now, suppose you have proposed a hypothesis which ultimately is tested and the test comes negative. That means, the hypothesis has a logical consequence which can be tested; it has been tested and found to be wrong, which means the hypothesis is rejected.

That is not a disgrace for the scientist. That is, in no way, a disgrace for the scientist because it is a task of the scientist to propose as many hypotheses as possible.

If your hypothesis ultimately turns out to be false, it is not a problem at all. Science can progress on the basis of that attempt, in the sense that if you have made a hypothesis that ultimately has been tested to be wrong, nobody else will make that hypothesis. A lot of scientific time will be saved and by actually proposing the hypothesis and testing it, science actually increases its knowledge base.

So, it is a fruitful pursuit to propose a hypothesis which might ultimately be tested wrong, false. To give another example, in cosmology there were two competing hypotheses. The observation was that we see the galaxies receding from each other with enormous velocities and from that observation, there were two competing theories: one was called the steady state theory other was called the Big Bang theory.

Let us take the Big Bang theory as an example. The Big Bang theory said that all the galaxies are receding from each other and therefore, if you look backwards they were closer to each other. And if you look further backwards, they were further closer to each other and that if you extrapolate in time, you reach a condition when they were all together in a very compact object, ideally of infinite density, infinite temperature. That kind of situation. From there, it has expanded to create the today’s universe. That is the structure in very brief.

What is the falsifiability criterion of this theory? It is easy to conceive that, because if this theory was correct, it should be able to tell when this Big Bang happened. They say that it happened around 15 billion years back. So, 15 billion years back this Big Bang happened and therefore, one falsifiability criterion should be that there should be no object in the universe which is older than 15 billion years.

So, the way to test the theory would be to look for objects that are very old. There are stars that are very old. There are star clusters that are very old. One can try to figure out by calculating how much time it takes to burn up the hydrogen that is present inside this or that star. There are ways of calculating the age of stars. If you can ever find one star, that is older than 15 billion years, the theory is definitely false.

We also see clusters of galaxies. Clusters of galaxies: in totality that is a structure, and definitely it takes time to form such a structure. The galaxies have to physically move from one place to another in order to form that kind of a structure. If we calculate the time taken by the galaxies to move into that kind of a structural form, and find that it is bigger than 15 billion years, then definitely the theory is false. So, all these theories have falsifiability criterion.

For example, starting from the premise of the Big Bang, people predicted that one of the logical consequences of the Big Bang would be that there should be a low temperature microwave background radiation. And that radiation was ultimately found in 1965 by Penzias and Wilson.

So, there was a premise and there was a valid logic, and there was a conclusion. Then this conclusion was tested to be correct. Would you then say that the premise, the Big Bang theory, is proved absolutely right? No, because of the situation that, even if it is a incorrect premise, using valid logic you can obtain a correct conclusion.

Therefore, what happened was, it increased scientists' confidence in the Big Bang theory. People started working on the other logical consequences of Big Bang theory. People started researching on Big Bang theory. But it was still a provisional acceptance. It is not a proof of the correctness of a theory.

But notice that, when the premise was proposed, the Big Bang theory was proposed, the falsifiability criterion was in-built. This is important: the falsifiability criterion has to be inbuilt in a theory.

Similarly, the steady state theory. Those who proposed the steady state theory very clearly laid out what are the falsifiability criteria of their theory. So, the lesson out of this is that, whenever we propose a hypothesis or a postulate, we always should very clearly state what are the falsifiability criteria of the hypothesis or postulate.

Only when the logical consequences of the hypothesis or postulate that are experimentally or observationally testable, these are tested and we find that corroborates the expectation from the theory, then that increases our confidence in the theory. That is a point. So, we come to the conclusion that in theoretical work, a very important consideration is to formulate the falsifiability criteria.

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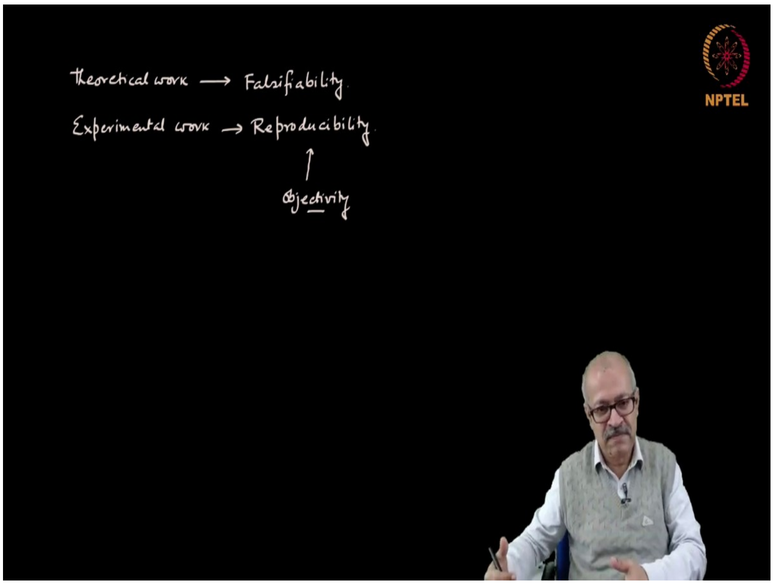


In a similar way, as in theoretical work you have to worry about the 'falsifiability' criteria, in experimental work, we have the concept of 'reproducibility'. This comes from the objectivity demand. The demand is that, any experimental result must be reproducible, because the result is coming from objective reality, the material processes. And therefore, the result from the material process should not be different for me and for you.

Any experimental result must, therefore, be reproducible. If it is not reproducible, then it is not a scientific outcome. And because of that, a scientist cannot say that 'I got this result because of my own personal experimental expertise', cannot say that 'it happened because of chance', 'it happened because I am so great that I could do it, you cannot do it'. These things are not possible.

Whenever you are doing an experiment and reporting an experimental result, you have to clearly state what are the conditions that you created where this particular phenomenon happened. Then, after publication of the paper, scientists all over the world will reproduce that particular condition and check whether the reported phenomenon, the reported results, say measurements, actually are obtained. So, reproducibility is a very important thing.

Science, as I said, bases itself on doubt. You have done an experiment and you have published the result. Immediately people will doubt it, will not believe it, and that is how science works. Whenever you see a paper, you have to read it and then doubt everything in it and check. How do you check? By repeating the experiment.

If you repeat the experiment and do not get the same result, then also you should report it in the sense that then you have a doubt that this result is correct or not. And in many cases, it has happened that when a very startling result was reported and then people repeated the experiment and found that they could not reproduce the result, then the paper has to be retracted. The scientist is disgraced and a lot of things happen.

For example, in the 1980s, there was a paper published in Nature, a very important paper. As you know, fusion can happen only in very high temperature and pressure that exist at the center of the sun or similar stars. A group in the University of Utah in USA reported that they have been able to produce fusion at room temperature. It was called cold fusion.

They said that when we dipped an electrode in a solution, at the surface of the electrode heat was produced, and it was produced by actual fusion of elements like hydrogen. They published the paper. There was a huge euphoria over that, because people believed that if that is really so, then that is the solution of all energy problems in the world. So, people jumped into it, tried to reproduce the result. But everybody failed.

And finally, a few months later, the scientific community reported it to the journal that something is amiss. We are not getting the same result and the journal confronted the scientist. They sent a delegation to that lab and the scientist was unable to reproduce the result. So the whole paper was retracted and it was a scientific scandal.

So, this demand of reproducibility comes from objectivity. When we talked about subjective and objective, we need to incorporate that into the process of doing science and it is incorporated by that. That an experiment should be reproducible.

Now in an experiment, we do not always just look at phenomena. We also measure numbers, measure values of quantities, values of constants, values of parameters. Suppose we measure something, and get a value 3.94. We report it. Will somebody somewhere else in the world doing the same experiment get the same number 3.94? No. It might be slightly different.

How can you ensure that your result is reproducible? Well, this is another issue that we will have to deal with when we talk about experiment and measurement. This is an issue we have to deal with. I will come to that. But remember, this is an issue that we need to deal with: that the experimental result should be reproducible and in many experimental work we measure quantities.

If we measure quantities, then when we report that result, it should be reproducible. How do we make sure? How do you ensure that result is reproducible? That is another issue we need to ensure.

So, we understand that the demand of theoretical work is falsifiability; the demand of experimental work is reproducibility. Without these two conditions being satisfied, you cannot publish a paper. A theorist has to worry about falsifiability and an experimentalist has to worry about reproducibility. Therefore, an experimentalist always has to report the complete condition, all the parameter values, all the background conditions, that went into creating that result.

So, as we go into the actual method of doing science, the scientific method, we have to keep these issues in consideration.

Just let me summarize before we go into that.

A. Whatever we do has to be objective and we should not allow our subjective beliefs and inclinations to influence our experimental results.

B. Whatever we do should be based on material processes and phenomena. That is the demand of materialism.

We do not base our theories or hypotheses on something that is imaginary, which is not based on material processes or phenomena. In fact, science went through a lot of turmoil when that changeover happened. Because initially, when people faced questions like, ‘how did the solar system come into being?’, ‘How did the Earth come into being?’, ‘How did life come on Earth?’, and so on and so forth, the ‘origin’ kind of questions, people had all sorts of non-material ideas. It took a long time to shake off those non-material ideas and focus on what can be the material process by which these could have happened.

The solar system could have been born, life could have originated, by divine intervention. We had to get rid of all these idealistic ideas and focus on the materialistic processes and then only we could find the answers. Science works that way. Science tries to find out the cause of every event and the cause is to be found in material processes and phenomena.

Remember, we have learnt that, for anything there is only one cause. There is no plurality of causes. This only one cause, which we have to find. Before we have found the cause, we guess various possibilities, and these are our hypotheses. Then we have the ability of identifying and eliminating the wrong hypotheses. That way we eliminate the wrong ones and we ultimately home onto the correct one.

Correct one or not we do not know. We get an answer which has not yet been proved to be false. So, science works on its ability to identify and eliminate wrong ideas and therefore, the method of science essentially comprises proposing and generating as many ideas as possible, right or wrong.

You will see that (in the next class I will come to that), there are scientifically accepted methods of doing the guess, scientifically accepted methods of proposing hypotheses. And then we'll come to scientifically accepted ways of testing hypothesis.

Through that we eliminate the wrong ideas and inch towards the truth. That is how science works. In the future classes we will learn how actually this is done.