Research Methodology

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Lecture - 23
What Scientists Actually Do, Part 01

Now that we have understood a few important issues in philosophy that concern the actual scientific activity, we need to understand what scientists actually do.

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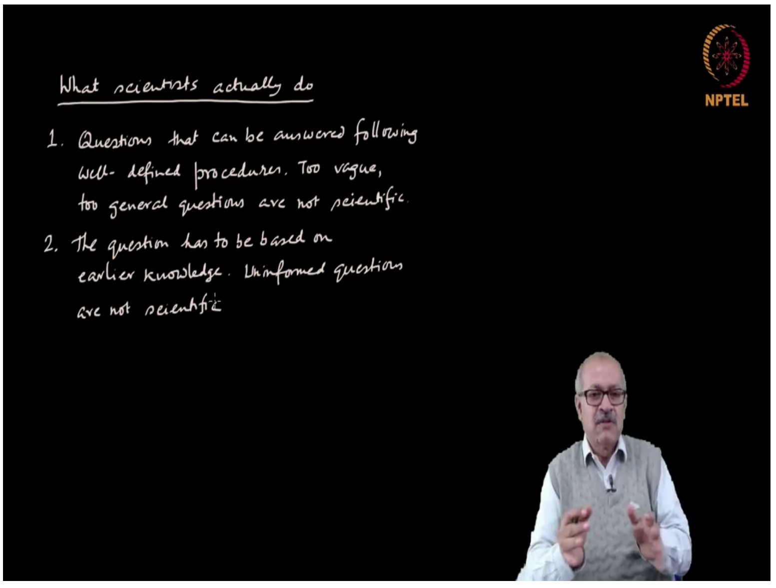

What scientists actually do? While we deal with this, you have to keep in mind whatever we have taught in the philosophy part, because the philosophical grounding actually dictates how we do our science. And we have learned that during the middle ages, the main mode of thinking was: ‘believe, do not question’, while in the Renaissance and the post-Renaissance period the main mode of thinking that emerged was: ‘question, do not believe’, ‘have doubt about everything’, ‘test everything’.

So, you notice that, questioning is at the root of all science. Therefore, all scientific research starts with a question. Always. All the time a scientist is trying to find the answer to a question. It is said that asking the right question is about 80 percent of a research work. So, one has to cultivate the faculty of asking proper questions.

The difficulty is that, through your educative process, through school, through college, all the time the questioning mind is essentially suppressed. The natural questioning mind is suppressed. It is unfortunate, but it is a fact. So, while a child, 3-year old, 4-year old, is always questioning the parents about everything around them, but as the child goes through school and college, the questions go down, and they no longer ask questions. This is detrimental to the health of science. So, while a student prepares himself for a career in science, one has to rejuvenate the faculty of asking questions.

So, what I am trying to drive at is that, all research starts from a question that the scientist has in mind. But all questions are not scientific. Therefore, one has to learn to distinguish between an unscientific question and a scientific question. Now, what qualifies a question to be scientific?

The first point is that it should be a focused question. It should not be too vague, too general. It should be such a question whose answer can be sought by going through a systematic process. The characteristic of vague questions, too general questions, is that you cannot conceive a possible research procedure by which you can get the answer.

‘What is the meaning of everything?’, ‘What is the meaning of life?’, ‘How did everything come into being?’, This kind of questions are vague questions, too general questions, based on which you cannot do any scientific research. You can ask, ‘what is the origin of this?’. You can define the origin. ‘What is the origin of that? You can define the origin. ‘What is the origin of the moon?’, ‘What is the origin of the sun?’, What is the origin of all that you can define?

But if somebody asks ‘what is the origin of everything?’ Well, each one has a different origin and therefore, ‘what is the origin of everything?’ is too vague, too general, and a meaningless question. So, that kind of questions we do not ask. It has to be questions that can be answered following well-defined procedure. So, too vague, too general questions are not scientific.

For example, idealists tend to ask this kind of too vague, too general, questions and claim that they have the answer, while actually these are not really answers. Second is that, science has build up a body of knowledge through the struggle of scientists over millennia and we ask question based on whatever we already know.

So, we ask questions based on earlier knowledge and then we seek answers to new questions whose answers are not known to mankind. And therefore, the question has to be based on earlier knowledge. We learn these by reading books, by reading papers and journals, through sources on the internet and so on and so forth. But you have to learn whatever is known. You have a particular issue in mind and on that you first have to learn whatever is already known, and then on that basis, you have to ask a question.

So, uninformed questions are not questions, are not scientific. Uninformed means: supposing something has already been done, but you do not know that it has already been done. You have that question. That would not be considered a scientific question, because already mankind knows the answer. So, you have to know what is already known to mankind by whatever means available. And only on that basis, you have to ask a question, whose answer is not known to mankind. That is a scientific question.

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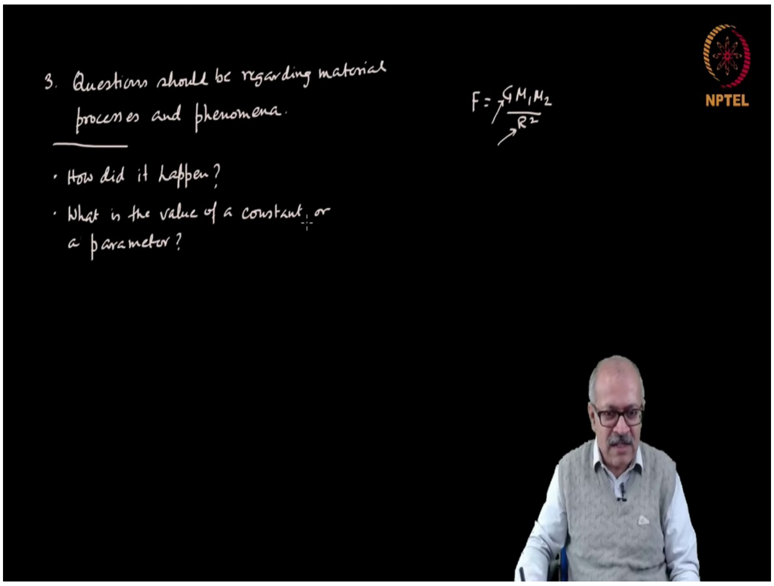

The 3rd issue one has to keep in mind is that, science bases itself on materialism, as I said. Therefore, the questions that we ask should be related to material processes and phenomena. But people harbour various types of beliefs and have questions regarding those beliefs. For example, miracles. For example, ghosts. For example, miraculous powers of stones or planets on our lives. These are unscientific beliefs that people often harbour, which are not related to material processes and phenomena. And those would not form the basis of any scientific question.

So, the question should be regarding material processes and phenomena. In this, no personal beliefs should have any role to play. When a scientist asks a question, it is based on certain observations, certain things that happened, or earlier research has indicated the certain possibilities exist. And on that basis one can ask a question. But these are always related to material processes and phenomena. These are not any imagined things like whether or not mind power can bend spoons and things like that. People have such beliefs, those are not subjects of investigation of science.

And one should not say that science has not disproved these. No, because science does not even care about these, because it is only wastage of time. Science does not care about anything that is beyond material processes and phenomena.

So, these are the three requirements of a question to be scientific. Now, what kind of questions do we ask? The kind of questions we ask can be of ‘how did it happen’ type. How did it happen? ‘How did it happen type’ questions, for example, is ‘how did the Himalayas form?’ Or ‘how did the moon come into being?’ ‘How did the Indus Valley Civilization come to an end?’ ‘How did life originate on the earth?’ These are ‘how did it happen’ kind of questions.

I will show that, in answering questions of this type, ‘how did it happen’ kind of questions, science follows a very well-defined procedure of formulating hypothesis and then testing hypothesis and so and so forth. I will come to that later.

There are certain questions related to ‘what is the value of a constant or a parameter?’ For example, the gravitational constant G in the Newtonian equation: force is equal to G M1 M2 by R square, here the G is the gravitational constant, and one may seek to find its value.

One may also seek to find a value of, for example, the distance between the sun and the earth, say, this is the earth, this is a parameter. So, G is a constant, R is a parameter, M1 M2 as our parameters, and one may seek to find their values so that one can calculate the value of F. So, what is the value of a constant, or a parameter? That constants measurement, I will come to that later. But notice that the question is of ‘what is the value’ kind.

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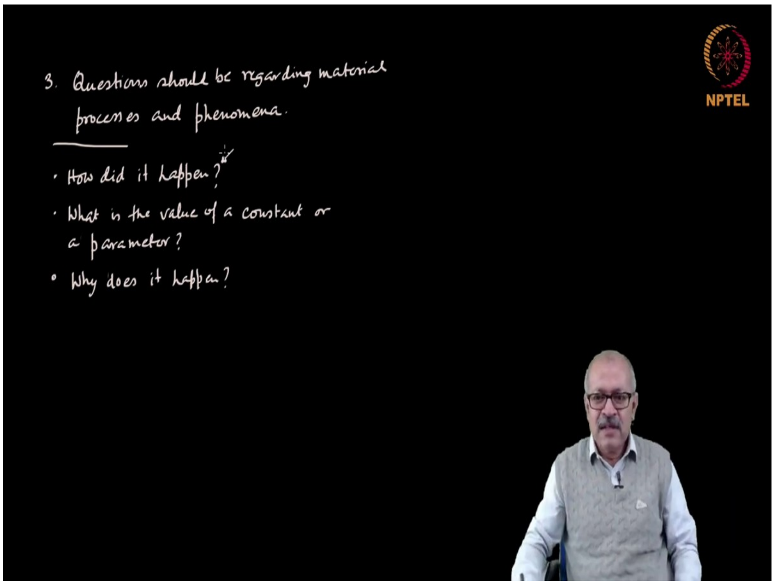

The third kind of question is the 'why' type. Why does something happen? For example, why is a leaf green? Why is the sky blue? Why do we see only one side of the moon not the other side? Why does sugar dissolve in water, but sand does not? These are the kind of 'why' questions that we often encounter and we seek to give answer to the question.

So, you would notice that a question always starts with a 'how', 'what', 'when', 'why', this kind of questioning words, and always ends with a question mark. This is something, I know do not know why, many PhD students miss. When anybody asks 'what are you working on', many PhD students say that I am working on solid state physics, I am working on the properties of these, etc. No you are always seeking the answer to a question.

Therefore, when somebody asks 'what are you working on?', you should state the question. 'This is the question whose answer I am seeking.' And that should always start with what, how, when, which—that kind of word and should always end with a question mark. So, remember always: a PhD student is seeking answer to a question and your area of work is defined by the question you asked.

So, whenever anybody asks you 'what are you working on?', always state the question that you are seeking answer of. The question is very important. This is how the questions are formed. There are very various types of questions that we ask. Now, after you have asked questions, you notice that the questions can be also divided into a few types.

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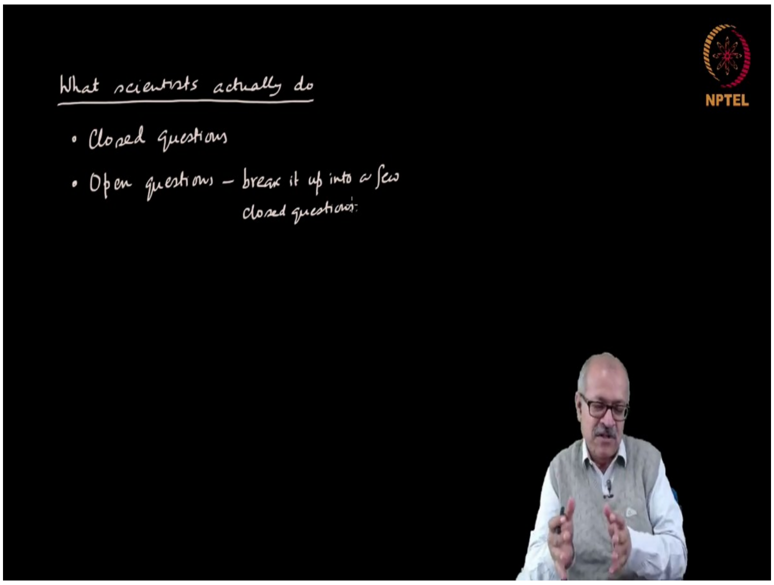

Questions can also be divided into a few types. There are a few questions, if you obtain the answer of that, the matter is closed. Which means that, the answer that you obtained does not prompt you to ask another question. For example, a question of the type of 'what is the value of the gravitational constant?' You measure it and after you have measured it, found its value, the matter is closed. Or, at most you might say that we need to measure it up to more number of decimal places. Yes, you can do that. More accuracy is possible, but not a fundamental question comes out of it.

Such questions are called 'closed questions'. So, what are closed questions? The questions whose answer does not lead to another question. The matter is closed. If you want to have other examples of closed questions, for example, what is the derivative of tan theta with respect to theta? You did not know that, you learned that, and that closes the matter. What is the value of the specific gravity of water at 30 degree centigrade? You have a question, you measure it, and that closes the matter. How many eyes does a fly have in a compound eyes? How many eyes are there? It is a question, a valid scientific question. You measure it and that closes the matter. Such questions are closed questions.

There are also certain questions, if you obtain the answer, that would open further questions. Such questions: when you obtain the answer of that, it will lead to further questions. This is a very important issue in science. You need to understand that there are certain questions that are closed questions. There are certain questions that are 'open questions'.

Let me give some examples of open questions. Why is the sky blue? You obtain the answer, but that will again prompt you to ask further questions, because that answer opens up new questions. For example, how does the genetic information contained in our DNA result in creation of individual body parts, for example, my spleen, my eyes. How does it happen? This is a very intricate question, difficult question, and you might have that question in mind. But you notice that, the answer to that question cannot be obtained in just one go.

There would be various small steps to obtain the answer to that question, and when the answer is obtained, that will open further questions. How does the stock market collapse in a particular country affect the economy of another country? A question, but open question. Is there any dark matter that is invisible, but still exerts gravitational influence on other bodies? An open question. Similarly there can be various open questions.

And remember, when a scientist does his or her research, he or she always has an open question in mind. But the way to answer an open question is that we divide that into a few closed questions and obtain answers to each close questions individually. And that allows us to go forward towards getting an answer to that open question. So, when we have open questions, we break it up into a few closed questions.

That is the standard procedure we take. That means, we have an open question in mind; we are working on that particular problem. But we break it up into smaller questions, each of which can be answered by a well-defined procedure. We ask our PhD students to handle each closed question and when one closed question is answered, we give them another closed question and so on and so forth.

The work of a PhD student often comprises obtaining answers to these closed questions. And through that, ultimately it opens the gate for obtaining answer to the open question. The problem that often happens is that, the PhD student gets to know only the closed questions. Therefore, they come out with an idea that these questions are all that are to be answered. No. The big picture is formed by the open questions and a PhD student should have a clear idea about what the open questions are, and how to break the open question up into a few closed questions and then obtain the answer to each closed questions.

For example, suppose you are in the last century, when we did not know why the sky is blue. And you have that open question in mind: why is the sky blue? If you want to obtain the answer to that question, straight you would not be able to. So, you have to break it up into closed questions, like, ‘is the sky more blue when you have more moisture in the air or is it the same blue all the time?’ ‘Does the blueness depend on the time of the day or is it the same blue all the time?’

I am not talking about cloudy sky, or dawn and dusk. I am not talking about that the other times. Is it the same blue, or does the blueness also change depending on certain parameters? For example, the time of the day. For example, the position of the sun. For example, the amount of moisture in the air, the amount of things in the upper atmosphere and so on and so forth. There are various things that can influence that.

The moment you have formed these closed questions, you would find that each question can be answered. For example, does the blueness depend on the amount of moisture in the air? Suppose you have this question. It is a closed question. Its answer is yes or no. You can obtain the answer to that question simply by devising some way of measuring the blueness. It should not be that, ‘today I think it is very blue’, ‘today it is less’. No. This is a personal perception, which can be influenced by one’s state of mind on that particular day. If you have fallen in love on that particular day, then the sky may look bluer.

Therefore, you should not consider that as a yardstick. There has to be some kind of a measurable extent of blueness: the frequency of light that is coming, and the frequency distribution, and where the peak is, and so and so forth. And then based on that you have to work. There is a dependent variable. The independent variable then would be the amount of moisture in the air and everyday you have to measure the moisture in the air and plot a graph. Today the humidity was this much, and the blueness was this much. Another day the humidity was this much, the blueness was that much. And finally, plot a graph and try to get some kind of a answer to that question: is it dependent on the amount of moisture in the air?

And when you have done that, the matter is closed. You know the answer. And that helps you to obtain the answer to the question: why is the sky blue? Basically you need to understand what does it depend on and then you can properly answer the question: why is the sky blue?

What I am trying to drive at is that, to obtain answer to an open question, you have to break it up into closed questions. But a student must have a clear idea about what the open question is and how it was broken down into the closed questions.

And at any point of time, a student is always working on a closed question. But there is, at the back of the mind, the open question which forms the big picture. And a closed question should be a testable question whose answer can be obtained in a short span of time following a well defined procedure.