Research Methodology
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Lecture - 30
Elements of Scientific Measurement, Part 02

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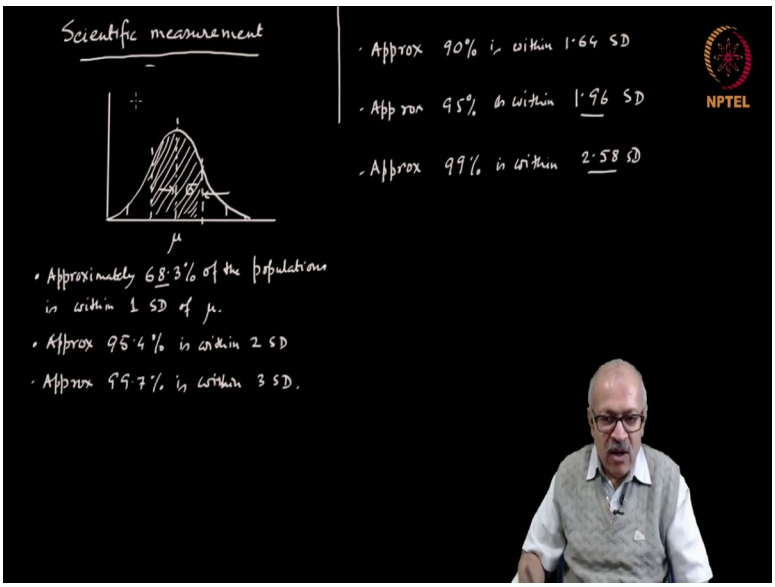

I described a few kinds of situations. Situation number one: we are trying to measure the mass of an electron. We know from theory that all the electrons have the same mass and therefore, we are trying to measure a constant. When we are trying to measure a constant, the variability comes from the random changes that we have, the random variation of the results that we can have.

But there are situations where the thing that we are trying to measure has a inherent variability, for example, the weight of a bird. It has an inherent variability. If a geologist is trying to find out the average density of the Earth's crust, then, obviously, he or she has to take samples from different parts and one has to be very careful that it is a representative sample of different types of densities.

So, whenever the thing that we are trying to measure has a variability, then we have to be very careful how we take the samples. So far we are talking about, we have a population out there and we are trying to take samples from there. If it is a population with some variability, there is additional consideration that, when we draw the samples, we have to

deliberately draw the samples keeping in mind a variability. Therefore, we have to make sure that, if there is variation, some chunk is at the higher level, some chunk at the lower level, then we have to draw samples from all of them.

In every field there are very well laid out prescription for doing that. In order to illustrate, let me give you the example of how samples are collected from the soil. Soil quality measurement is a very standard thing that agricultural scientists have to do all the time, and they have the same problem.

Suppose they have a large field in hand and from that large field, they have to find out what is the character of the soil of that field. But the character of the soil in this part of the field may not be the same of the character of the soil in that part of the field. Character of soil in the top layer may not be the same as the character of the soil one foot below.

So, we have to take that into consideration. How is it actually done?

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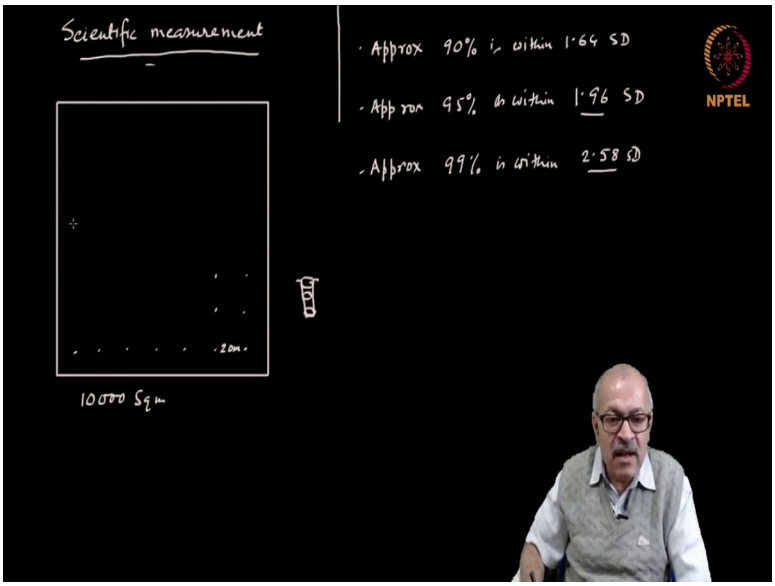

How it is actually done is that, suppose I have a field, suppose I have a square field like this. Suppose it is about this much, and I have been asked to find out the character of that soil. How do I do that? Because the character of the soil here will not be the same as the character of soil here here and here, it will be different, and as I said, at different layers it will be different.

So, what is done? What is done is that, we make holes every 20 meter distance. So, like this, every 20 meter distances, holes will be made. The holes will be like this at about 20 meter distances and soil will be collected from the top, from the middle, and from the bottom. If this is done from all the holes all around, then the soil that has been collected will be a huge amount of soil.

Now, that soil will be dried and will be spread over a hard surface, maybe cemented surface. Let me now use that this as the cemented surface.

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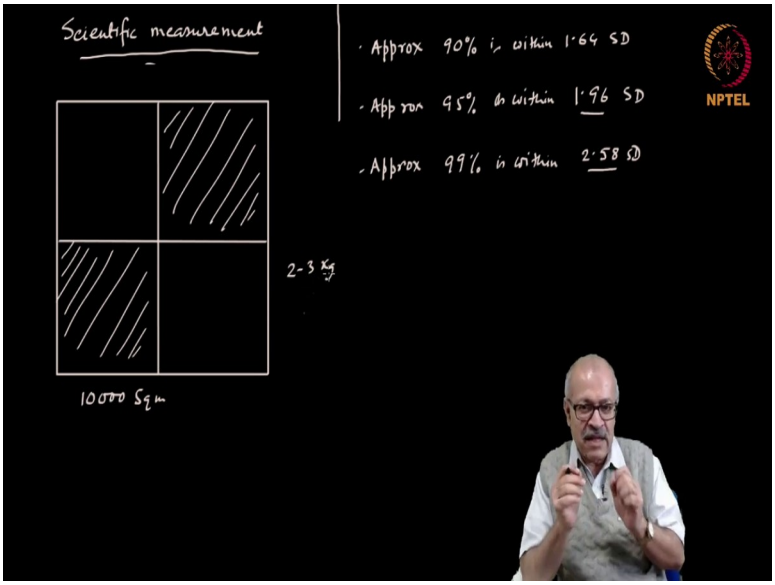

So, the sample is spread over the whole thing and then this is divided into four parts by doing like this. Then this part and this part are retained and the rest thrown off. Again the soil is mixed, again it is spread over the square area, again the same process is repeated. That means, you mix up everything, spread it, and then you retain the main diagonals and discard the off-diagonals, so on and so forth.

Ultimately you carry on this process until you have got something like 2 to 3 kgs remaining. When you get the 2 to 3 kgs, it is a reliable mixture of the soil collected from all parts of the field, as well as from the top, middle and bottom, and therefore it is a reliable sample from the field. But after this 2 to 3 kgs is obtained, it is further ground and it is seived through a 2 millimetre sieve. Finally what is collected, that is tested.

Notice, what we are doing, this is the standard laid-out procedure for the soil scientists. Similarly, for every field there would be similar very well laid out procedures, and using that we collect the samples.

If you have to collect the samples from a population of humans, we know the humans can be old, middle aged, children, babies, male, female. So, we have to collect from all the groups. We have to make sure to collect samples from all parts of the population. This is very important in sampling.

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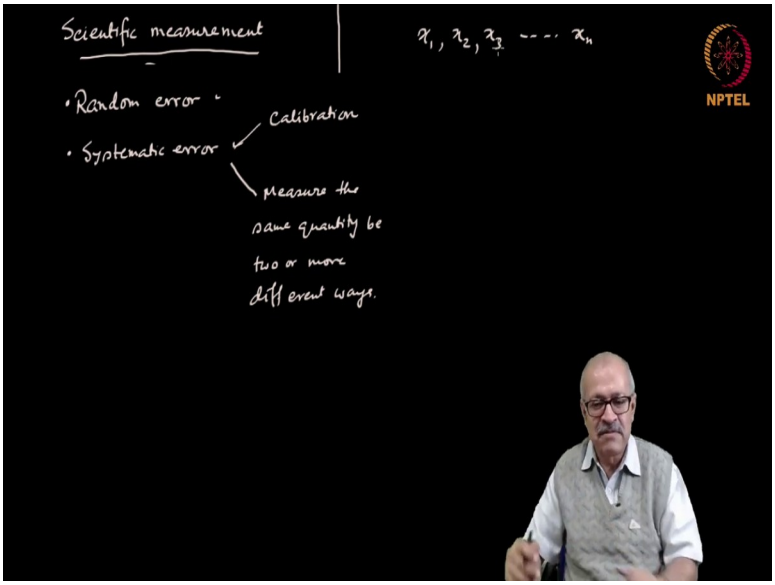

In any measurement there are two types of errors. The first is random error and the second is systematic error.

Systematic errors are those, which make the results that you obtain systematically differ from the actual population mean. There is a value out there, the actual population mean, and you are trying to get an estimate of that by obtaining the sample mean. Now, if there is a systematic error, there would be a systematic deviation of the sample mean from the population mean.

That can happen due to various reasons. But this is something that we have to somehow figure out and eliminate. Because, if a systematic error remains, then the results will definitely be wrong.

But random errors generally cannot be avoided. Random errors happen because of, you know, thermal fluctuations and effects like that, which are not within our control. Therefore, a scientist has to learn how to take stock of the random errors. So, systematic errors can be eliminated, but random errors normally cannot be eliminated. So, a scientist has to learn to live with random errors.

Systematic errors will depend on the area in which you are working. The systematic error for a physics experiment may not be the same as a systematic error for an Earth Science experiment, for example. Different fields will have different instruments used, and different systematic errors. But nevertheless, scientists have two general prescriptions for getting rid of systematic errors.

The first is calibration. Wrong calibration is the most common source of systematic error. Therefore, it is necessary to periodically recalibrate all the equipment that you use, because with age the calibration goes bad. With environmental condition, the calibration may change.

So, recalibration every now and then. It is necessary for every equipment. We scientists sometimes do rely on the data that a big equipment churns out, without bothering whether it is properly calibrated or not. So, it is very important to check the calibration.

The second is that, whenever possible measure the same thing by two or more different ways. Measure the same quantity by different ways. The advantage is that, it is very unlikely that the same systematic error will creep in, in two different instruments. Two different methodologies means, you will use two different equipment, and it is very unlikely that the same systematic error will creep in. So, if you get the same results, results within some tolerance, then you know that your results are reliable.

But if you measure by two or more different methods of measurement, and you get substantially different results, you know that there is a systematic error somewhere and you have to take care of that. So, generally, in order to avoid systematic errors, these are the two general prescriptions. But for every field the source of systematic error will be something and you need to figure out depending on the character of that particular field.

Random errors is something that you have to learn how to live with. As I said, always we take we set up the equipment, set up the experiment, in such a way that for every

measurement, we can take a large number of readings and can take an average. This is a fundamental prescription. Nobody can avoid that. Sometimes, when using big equipments, people miss out this particular point, because a 1 crore worth equipment and you have fed in a sample, it is giving some data and you are simply trusting that. You are believing that. I have put in the sample, it is giving the data.

No, what it has actually done is that, this equipment itself has within it, the built-in possibility of making multiple measurements, and averaging out. What it is churning out is essentially the average of multiple measurements. So, always remember that without multiple measurements and taking the average, you cannot get rid-of the random errors.

So, when we, for example, measure the resistance of a wire by applying different voltages, by measuring the values of current and then tabulating them, dividing the voltage by current, thereby we get a large number of values of x: x1, x2, x3. Each will have a random error in it, but the random errors in some cases will be positive, in some cases will be negative. Therefore, when you actually do the act of averaging, then the positives will cancel out the negatives and ultimately the effect of the random error will cancel off.

That is what the naive belief is. Common-sense logic will say that, if you have positive errors as well as negative errors, then obviously the positives will cancel out the negatives and ultimately you will get a reliable mean value. But the moment I say that, a few questions immediately arise. Before we end today's class, let me enumerate the questions that immediately arise.

For example, how many observations should we take in order for the result that we get to be reliable? Common sense does not immediately tell us any estimate of how many readings should we take. We actually get a large number of values x1, x2, x3 ... each value is different. Out of that, which one should we state in a paper? That is, how do we state the measured value? How reliable will be that measured value?

Can we state some kind of a degree of confidence that we have in that measured value? How do we state it, in the sense that, an experiment has to be repeatable? Repeatable anywhere in the world. Therefore, I have to state it in a form, so that anybody repeating the experiment anywhere in the world should get the same result. How do I state it that way?

If I state a number, another person doing the experiment somewhere else will not get the same number. How is it repeatable then? There has to be some way of stating the number that we measure in such a way that it is repeatable. So, how do we state it? Should we declare it as a range? If so, how big is the range? You know that we always use something called ‘error bar’. How big will be the error bar? How do we decide, how big the error bar will be?

When we state it with the error bar, our statement is of the form that ‘I am fairly confident that the value lies within this range’. What do you mean really by saying that ‘I am fairly confident’? Can you state a number as a degree of confidence? So, all these questions arise. Natural questions. We will deal with these questions in the next class.