Introduction to Uncertainty Analysis and Experimentation
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Module - 03
Experimentation
Lecture - 07
Experimentation – I

Welcome, to this course on Introduction to Uncertainty Analysis and Experimentation. Today we start the 3rd module which is on Experimentation. We will do this module in two parts, this is the first lecture called Experimentation I. Now, the very first question that would come to mind is why are we talking of experimentation in a course on Uncertainty Analysis.

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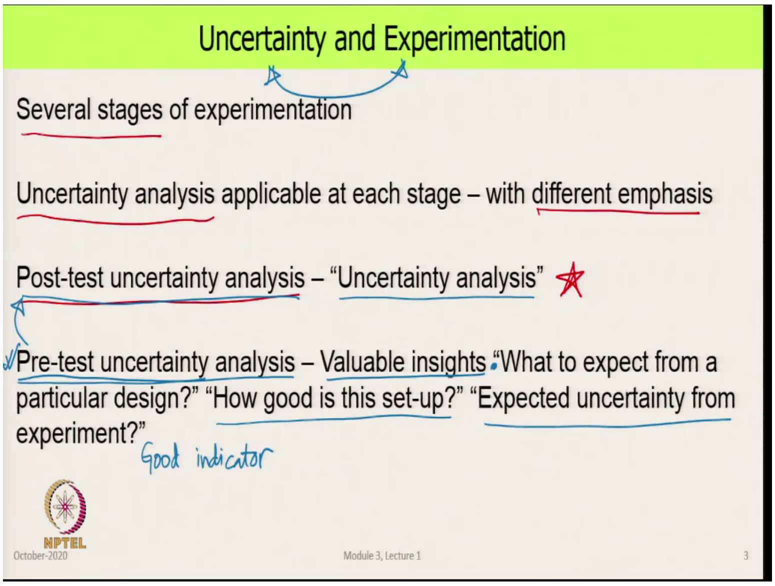

The reason goes like this, that experimentation has many stages. And we will see all these stages in a few minutes, each stage has a specific activity and starting from beginning to end we are encompassing a series of activities which starts by asking, what do I want and finally, we end by saying here it is and here is a report on that.

Now, in all these stages at different times, we use uncertainty analysis with different emphasis. Sometimes we want it just for a quick glance, sometimes we want to establish a firm number and at the end, which is what we call as post test uncertainty analysis. This is when we do a complete calculation of uncertainty in every measurement and the results, and present our findings and conclusions in light of those uncertainties.

In common parlance, when people say that uncertainty analysis or this is the uncertainty. It almost always implies that this is post test uncertainty. So, while this is quite common thing what is uncertainty? It always refers to the post test uncertainty, what the experimentation process encompasses is that besides doing the uncertainty analysis after the experiments have been done.

It can be a considerable assistance in everything that goes on before we even start taking data, and that includes setting up of our problem posing the question, saying how good an answer we want, designing the setup, debugging it in all of that pre test uncertainty analysis gives us very valuable insights.

For example, yes couple of questions here. We can say well what is what can we expect from a particular design? And I will illustrate that with a few examples in a few minutes. The idea is that in making an experiment, it is like a design problem many possibilities are there. There is no fixed answer and what you see is not something what we call the correct answer. Everything has got its own merits demerits and for some reason one particular design gets used.

So, how do we evaluate this? There are some real life issues, but then uncertainty analysis also comes in a very big way. The next question is how good is this setup? So, this could be an apparatus an equipment or an instrument or complete test rig with the experimenter or with one of their colleagues or in some other laboratory, or in some other industry. And, if you want to use that we need to know how good is it? Does it serve the purpose that the experimenter wants.

And, the answer to that will come quite nicely from a pre test uncertainty analysis. If at this stage we say that this setup does not meet my uncertainty requirements we do not even need to do an experiment we say cannot do it let us go away try something else.

And then there is of course, before doing an experiment this analysis can tell you. What is the expected uncertainty from this experiment? Now, this is a pre test uncertainty that we are talking of so, it is not exact, but it is a very good indicator of what that particular setup will give us.

The second advantage of pre test uncertainty is that after you have done it, when you do the post test uncertainty. One can use a lot of information from the pre test uncertainty analysis in the post test analysis. That means that doing the post test uncertainty analysis becomes a little simpler.

So, that is what is the connection. That there are many stages of experimentation, and uncertainty analysis comes in and helps us, in taking decisions and making designs, selecting instruments at different points in that experiment. And so, that is the link between uncertainty analysis and experimentation and that is why we have taken it up here.

Another good reason for taking it up is also that experimentation as we have seen in our definition earlier is a complete set of activities involving doing something or wanting to know something. And, often in what we go through in our education or even in our profession, we miss out on many of those. And so, in the end what we have is something, whose goodness and completeness we may always have some doubt on it. So, we will take a few minutes to see what goes on in what we call traditional experimental work.

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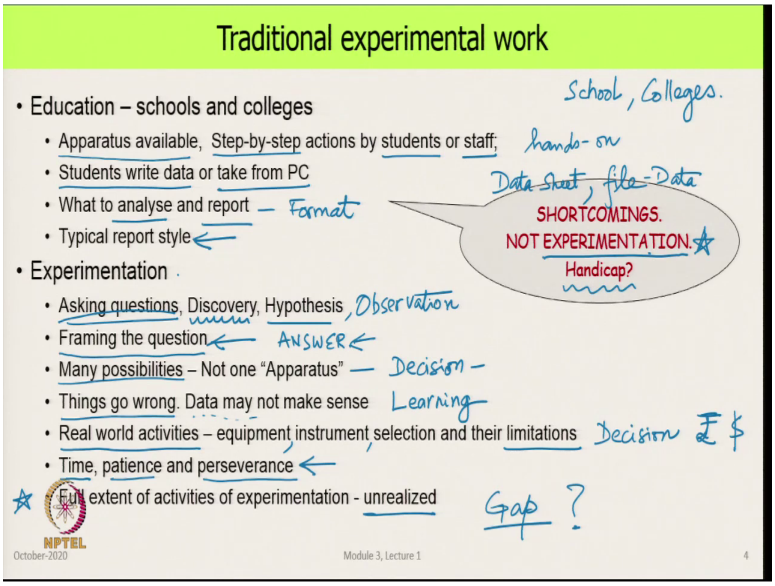

And, this is what one would typically come in doing experiments in school, science experiments say and even in colleges. The syllabus has got some theory, it has got something which says that you got to do these 9 experiments or 15 experiments, the name is given there. And, then we know that that setup is there we go to the laboratory do what we are told to do and get a number. So, here is what happens in the schools and colleges.

They have a laboratory in which the apparatus is kept, by apparatus I mean a complete setup rig where you just have to do something. You do not need to go about assembling the whole thing or designing it, or understanding why it has been designed that way that is not the point. Apparatus is there, and you are given a sheet which is a step by step instruction of what you have to do, what to write, what sketch to make.

And, then when you are doing the experiment some of the experiments are done hands on by students. So, the issue here is hands on and there are some others where the staff does the operating of the equipment and the students are told to record some data. So, that is what one does you go there you are told you have to take the you have to adjust, this to this value adjust, this to this value press this button start that thing and now note numbers from these gauges or indicators.

So, the students are given a form called a data sheet. It is a table in which they are told, what is it that we have to write. And as the experiment proceeds they keep noting things in that in, these days there are many experiments where the data is collected electronically and stored on a PC. And, then at the end of that there is no data sheet, but just a file which one takes or the software may be such that the data is there in the file, and using this they also make various plots.

So, what the students do is we take all of these things and that the teachers want them to do. You take all these things and they are told what they have to analyze that, see the variation of this with this and this with that and make a plot, and then they write a report. So, report is an elaboration of all the items that are there.

So objective, then there is equipment, procedure, data, then the analysis and finally, a conclusion. So, that report format has been quite rigorously been followed and we know that this is how the report should look like. So, that is what the style of the report was and after that there is an evaluation marks are given and that is the end of it.

So, this is what goes on. The thing is that there are many shortcomings in what this has been what we do. We learn a few things as teachers, if we are doing this we are teaching a few things, but still we are missing out on a lot of things which is what are the shortcomings. And by and large what we are doing here, this is not experimentation this is the point. The entire range of activities that was there, the student did not go through it. In many cases even in later on years, whether it is a thesis or in research there are sometimes we may miss out a few of those things also, but that is a little more complete in that sense.

And having learned experimental work in this way, that is what we are told is doing an experiment that is what do you have to do. That gives you an handicap in that, we did not learn or experience the full range of things that go on in experimentation which is what real life is about. So, here are some of the issues that do not come out in the traditional experimental work, the way we are taught.

All the experimentation all research all query, education in general begins by asking questions. By questioning what we see? That is the other important thing observation. We observe what is around us ask questions frame them as a hypothesis and we so, in all of this we do not know the answer. So, there is a doubt and that is why we do an experiment.

So, there is an element of discovery in the very process of experimentation. In contrast what one does in the school thing here? Is that the same apparatus has been used year after year after year, reports are available they know, what the answer has to be like and there is no element of discovery surprise or something else happening. So, this is mixed up.

In general whether it is education whether it is research or whether it is even R and D later on or even in the industrial setting, the most important thing is framing the question. We have to ask what is it that I want? That will decide what answer you can expect or answer you should get. And this is very tricky, the question is not framed properly the answer may have no meaning at the end to what we actually wanted to do.

So, this is a very important part of education and then professional work that, we posed the question very correctly precisely and be clear that the answer to that will solve or help us in taking the decision that we want to take. The next thing that the school education does is that it gives you one apparatus to work with in reality there are many possibilities. We can answer this question; with many designs of the apparatus none of them are wrong, some of them are better, which one to use that depends on the experimenter's decision.

So, we have to at many stages here we have to take a decision, and a decision has consequences. Sometimes it works out well; sometimes it lands you in trouble well, then you go back do it all over again. That is what is experimentation in the first place. So, that is what is things go wrong, in the real world no matter what we have in life nothing works exactly the way. It is supposed to work or the way we have been taught, things go wrong in an experiment many things will go wrong and that is how we learn.

So, that is an important part of learning making mistakes, things going wrong in the laboratory hands on work. Sometimes the data that we get from the experiment may not make sense. Common sense is not it you just look at it and say no this is not the way it should be something else.

This process in the school did not give us the option of deciding what to use to make a measurement. So, what was missing is some real world activities like equipment selection, instrument selection, and which one of these to get which will decide what is the limitation of the instrument, which will decide the limitation of the experiment itself. So, again here there is a decision to be made. And buying equipment and instrument this also has a cost implication.

Then, there is something which is some sort of intractable thing, but very important in the real world we do it we experience it, the laboratory we do not do it that much which is that it takes time to do a good experiment, takes a lot of patience, lot of perseverance. So, it is not that we confidently go to a lab and know that it will work and we will get data. In this case things will not go wrong you have to be patient, sometimes the experiment itself takes a long time things go wrong you have to be at it again and again, and that is what experimentation gives us.

And so, in a nutshell what we have is that in, what we have gone through as education in the in laboratory or in the experimental work. We have not realized the full extent of all the activities that go on or that comprise experimentation. So, there is a Gap. So, what is this Gap? And for that we need to ask, now what is the nitty gritty details of experimentation?

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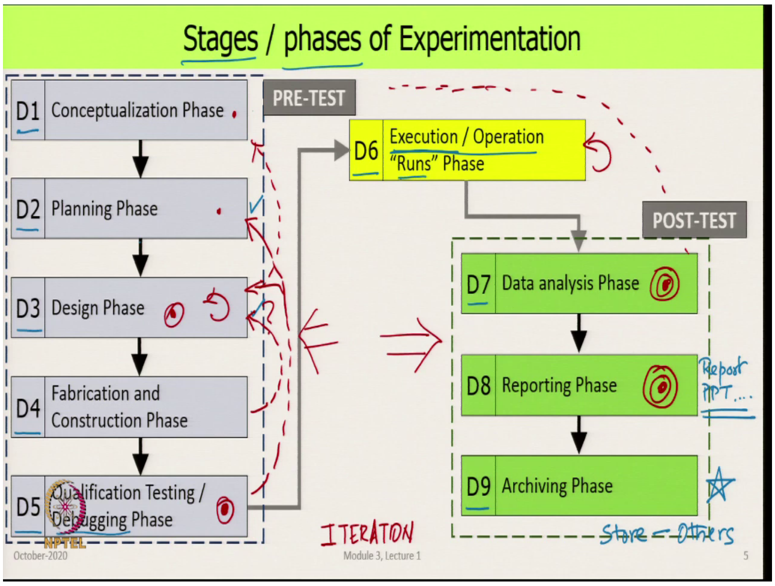

And that is what I have depicted here; experimentation is broadly classified in 9 stages. Some people call it stages some call it phases, we will use these interchangeably they mean the same thing. A stage or a phase is the particular set of distinct activities, where we do something and come out with an outcome. So, here are these phases I will list it out and then we will go through each one of them in detail. So, we will revisit each one of them.

Experimental work starts with the first phase, which I put here as D 1 this is a conceptualization phase. That means, here we sit discuss not just with scientists, but with different people and figure out what is it that we want to know, what is the question, what is the data that we need, where is the need for doing an experiment as to what data I want? This comes out at the conceptualization phase.

So, the end of that we said look I need to do an experiment, because I want this particular data. In the concept phase we said why we wanted that data is also formed up. In the next phase once we have done that, we start doing the planning. And saying that if I need this data and I need certain experiment to be done.

What options do I have, how do I go doing it, how many experiments do I need to do, what are my constraints on time, space, personnel, which concept design should I use? All of those questions will come up in the planning phase.

So, again these are again paper pencil or you can say desk type things, where there are a lot of discussions and talking with different people, looking at things and of course, it is all open book open notes. So, you are free to read up anything you would like to come to your conclusion. The more you read the better informed you are the better decision you are able to take.

Once we have decided at this point at the end here, that this is the experiment set a concept that I need to have this is how I will do the experiment, this is what I will measure. Then, we say let us go and design it in detail and design means a detailed engineering design. So, that takes us to the next phase which is the design phase.

So, here we start by saying that look this is the measurements I want to take, from which I want to make this calculation which I want to make for a decision. Now, what should be the size of it, what should be the materials, how do I connect them, what are the safety features that I need to have, which instruments I will buy all of that comes into the stage? And at the end of this we have a full fledged detailed design of the setup on paper, we have not made anything yet, we may have seen some things that other places, but right now it is on paper or computer.

So, at the end of this we have a complete design, I mean which says that look this is how it will look, this is how it will stand, this is what it needs? And, then it also generates for us all their equipment and material requirements that we need to have to make it. Once all of that is done we are ready now, to go into the next phase which is the D 4 phase which is fabrication and construction.

So, now, we start based on this design we start buying items, we buy materials finished, semi finished, raw materials, some readymade instruments, data acquisition systems, data cards, all sorts of things that we have listed in this comes into play now here, we procure it. And, then we have start putting everything together to make the setup that we want that is the fabrication and construction phase.

Once, the setup is done it is not that we just go and start taking readings. We have to ask the question does this setup do what I wanted to do and how do I prove it? The proof of that has to be in data, and that takes us to the 5th stage which is the D 5 stage. Where, we do qualification testing and debugging. So, here what we are doing is we know that there are certain things which everything has to obey, we check in the real world with the setup does it do it or not.

From a knowledge of the physical processes that are there, we know that this thing has to happen something has to happen in certain way under well controlled conditions. Because lot of people in the past have done it, we need to check that and verify that our setup also does that. During this phase we have used the word debugging, it is like debugging a computer program means you wrote a program, but you want to make sure that under various things it will work properly.

If there is something off or there is something out of range, it will tell you it is something out of range and not just hang up. Same thing we do with experimental setups. So, that is the 5th stage and at the end of this stage our setup is ready, we have done the qualification testing. We have done the debugging and we are now sure everything works; works properly and gives the quality of data that we expect which is the which addresses the reason why we started from here in the first place.

So, now we have that apparatus ready which in schools and colleges is already there in front of us. So, all of this we missed out. Then, we go to the next phase which is what when we do more often and call it doing an experiment, which is the D 6 phase which is execution and operation or we say runs.

So, all we have done is comes from this stage, and now we are varying para parameters taking data and that is what is each one of those thing is called the run. And, doing all the runs one after the other, which is all the executing all the experimental experiment at different parameters. This is called the execution of the experiment or operation of the experiment.

In the course and the notes, we will largely use the word execution, is the execution phase. So, text we take all the data like we do in a college laboratory we go there sit there take all the data; that means, we have executed D 6 phase. Once that is done we have all the data with us hard copy, soft copy whichever format it may be, as pictures or files or whatever then we go to the data analysis phase.

So, we sit with that all those numbers, pictures, all types of videos whatever else we have taken start analyzing it and see what it means. And, we analyze it for basic checking and also to calculate the results from which we wanted our data in the first place. So, at the end of this we have all our results done, we have made our plots, graphs and conclusions and if there were hypotheses that were being tested, we have also got the answer to that. So, what we started off in D 1 got done in D 7.

Once that is done, we go to the D 8 phase which is the reporting phase. So, this stage we all just had lot of numbers, lot of files, lot of charts, at different locations. We put them all together and to start we make a report, or presentation or poster or anything else for doing two things, putting everything together in one place.

And, the most important part is communicating our findings and results to others. If, it is within an organization you are maybe reporting the results to others to take a decision. If you are doing research as a student, we are reporting our results to say a journal or a consults.

If you have done the experiment as part of a design consulting work for some other corporation, you are giving them the report. They are the ones who need to understand it, and appreciate that what was given as a query at the concept phase has been adequately answered and reported in the reporting phase. After D 8 stage which is the reporting phase, we come to the last stage which is archiving.

What one does here is that all the data that we collected raw data that is calculated data or the graphs, plots, everything that went right, everything that went wrong all results from the debugging phase, everything from the design phase, all the drawings everything we must archive. That means, we must store and for future use, this is very very important. If you do not do it few some months later or when people change, they may end up doing the whole exercise all over again, which would not be needed at all.

And, we are doing all this for others. Few years down the line someone wants to relook at the data, they should be able to not only get hold of the data, be able to make sense out of it and interpret and re verify what we had done, that is the archiving phase. Now, I put everything here as a very linear one way process in reality this does not happen always like that.

Sometimes after setting the question here, we start going into the planning or the design phase and find you know there is a problem. The way the question has been posed it is very difficult to do make that experiment. So, we go back and ask whether do you really need to go things that way, can we look at it in a slightly different way and takes an iteration there.

Within the design phase we start taking parameters and say, well we had wanted to do this with certain objectives. Some of them are difficult to achieve, do I have an option can I make some modification to what had been decided earlier. Then, we make go to the procurement and fabrication phase, and we find that some things are not available in the market.

Something we thought was available is now discontinued it is an old model a new model has come, I have to redo everything. So, from here we end up getting back to the design phase to change the design. Sometimes we see that the design that was made was very expensive. So, in this phase we say well look there is an alternate material can I use that. So, like this there are a lot of iterations happening.

Then, in the qualification test we find there are no something does not meet our requirements, this could mean that we may have to go back all the way either to the design phase or maybe even to the planning phase. That means, that you are restarting the whole exercise all over again in some sense, but that is what it is.

So, there is a lot of iteration involved here and of course, the big iteration would be that you would look collect all the data, analyze the data and find that it does not answer the question that we wanted. The data is telling us something very different.

So, this may even say that do you know go back, and start a new thing all over again or abandon the idea that you were looking at. So, the thing is that within the execution also say, we run a few experiments and find out something does not make sense we make a quick analysis of the results.

We may have to go back and maybe make a small change here or a big change there or change an instrument or change the program that is collecting the data. So, within this there will be iterations. Designed by definition always has lots of iterations you never get designed in one go.

The point is that these stages although they have been organized in a sequential manner; there is always first a lot of iteration. We often do the same thing over and over again many times before we finally, converge to something, and maybe at some point we say no we have done enough of it, let us take a decision and go ahead and see what happens. So, that is what it is. So, all these stages can be organized in two broad categories one is stages D 1 to D 5 and the second is D 7, D 8 and D 9.

So, these are the stages that are before the execution phase and these three are after the execution. And that is what we have been calling so far? This is the pre test set of activities. So, these are all the activities that are done before we start taking data, and after we have taken the data we come to this next stages this is what is called the post test.

So, these are the pre test activities or the pre test phases on this side here, and on this side this is the pre test set of activities these are the post test set of activities. And, as we go through the discussion on each one of them in detail, we will see how uncertainty analysis comes in at each and every place. Its most extensive and detailed use comes here in the design phase, then in the qualification and making up of the test plan and of course, in the data analysis phase.

These are extensive uses of uncertainty analysis, in the others we go by largely our experience, or ballpark figures, approximate figures to make major decisions. Of course, in because after data analysis we have done it, and then while reporting we must include the uncertainty. So, this tells you that in all this work or what is experimentation and why uncertainty is important consideration at different times.

So, now this is all very what you may call as you know very conceptual way, very theoretical way of making phases, I will give a couple of examples now to illustrate what we have been talking of.

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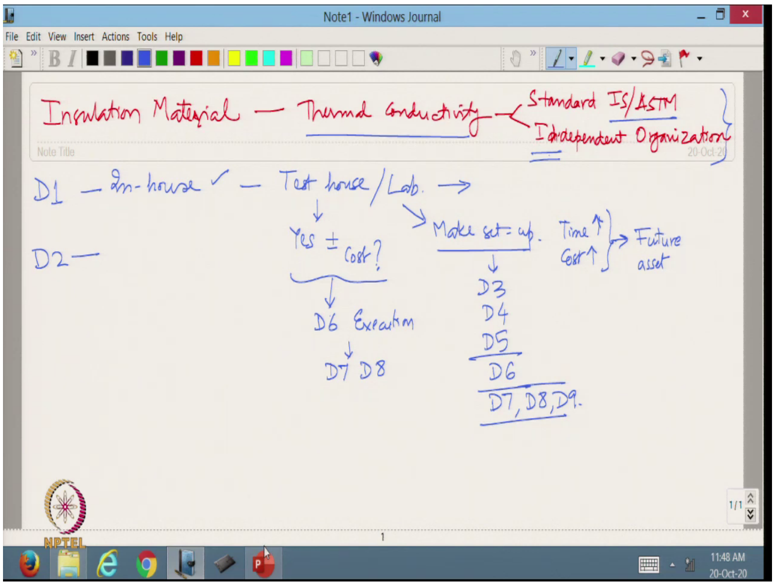

So, we start with some example and this is a real life example where people came to us and said you know, here I have an insulation material. And there is an company that manufactures this insulation material and says, I sell it to such and such an industry. But, that industry wants me to give a certificate about its thermal conductivity.

This is part of the contract I got this order, but they said. Now, I want you to give me the certificate of the thermal conductivity. And, they specified a few things more on that that this has to be done as per a particular standard, it could be an IS standard or maybe an ASTM standard. And, it should be from an independent certified organization, so that what they had to do.

Now what options did this organization have, they may be just middlemen who would buy the material from somebody and sell it to somebody else. Or there could be someone who manufactured, it themselves and then they market it and sell it. So, if you see that if you had to look at the different phases that they have to go through this D 1 phase conceptualization.

So, here all the marketing people, the engineering people, the manufacturing people, they all sit together and say look we got to solve this problem, client wants the thermal conductivity of this material, as per the standard and from somebody else.

So, one option they would have had well if we have an apparatus in house, we could have used it, but because of this constraint it cannot be used. If this constraint were not there from the client side, they could if they had the apparatus with themselves, they could have done it. Because, it is not possible, because of this constraint they have to go to an external agency.

So, they can go to a test house, or they can go to some other laboratory which could be in a say a research lab or in an academic institution. And they say look this is what I want these are my constraints. And, then they would look at it and say well I have very many options possible some test house says yes, I have such an apparatus conforming to this standard and I can do it for you. That is problem solved, but then you need to agree to get the payment and you have to figure out, whether the uncertainty is as per the ASTM standard.

If they go to some other organization they may say, well you know you know we have the capability to do it, but we do not have the setup. You will have to pay for it, then we can make the setup and we will make it as per the standard. And, then we will make the measurements and give it give the data to you.

So, now, the organization has two options this may take more time maybe more costly. So, the time is more here and so is the cost where as these people would say this is my cost we do not know how costly this may be, but time could be relatively short much shorter than that time.

So, now the organization has to make a decision and say look where am I going to get it done. If I get this thing done, I may have a setup which I do not get anywhere else very quickly. So, for future use this may be an asset for me whereas, if they just wanted a one shot deal this could be the answer. So, these are non technical issues, both of them are meeting ASTM standard and the independent organization criteria.

So, this is a sort of planning that they will do, to decide what is it they want to do. If they want to get it made, if they want to do this part, then they would straight away ask them for some debugging type of a thing and skip some of the design phase, fabrication phase, and maybe even the debugging phase may be skipped if they are a test house. And, straight away go to the execution phase which was D 6 execution. And, then they would give the test certificate. So, the reporting would come from there D 7, D 8 will come from the test house itself and their job is done.

So, we skip certain steps when we go this path, but it is still a part of the total experimentation process, in this case things are different. After we decide to fund this lab to make the setup, they will go through all the phases D 3, D 4, D 5. They will make the complete design, they will procure the equipment, put it all together do the debugging and then finally, come to the execution phase then give you the data and its analysis.

So, this route takes up all the phases that we have seen in the experimentation scheme of things. Here we skip a few from D 2, we go straight to D 6, D 7, D 8 here we go D 3, D 4, D 5, D 6, D 7, D 8, D 9. So, that is one example.

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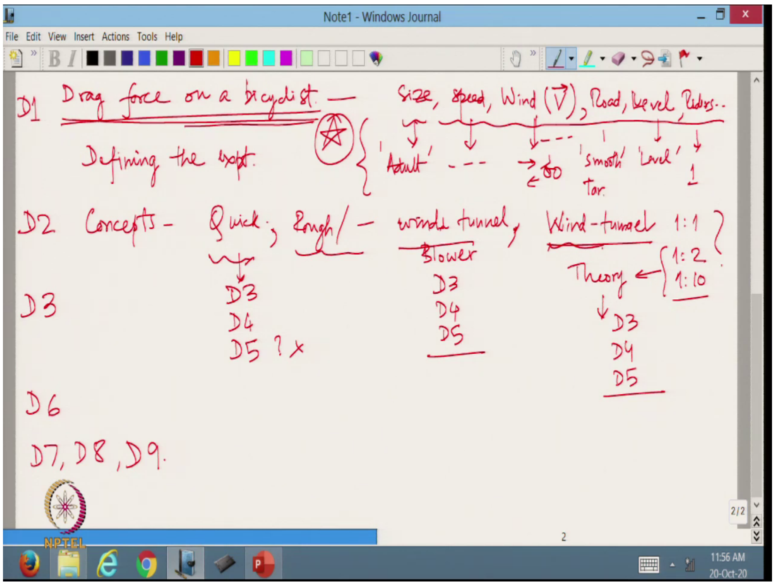

Now, we take the second example and this is say we want to do a measurement of aerodynamic drag force on a bicyclist. That means, you are asking when a person is doing cycling, how much is the aerodynamic force. So, how much more energy does the cyclist need to expend, when there are different wind conditions on it.

So, the way this question is posed it is very broad. So, we need to be a more specific. So, the person who wants this data will have to now say well, look this is fine, I can just put this as a question and you get me the data. Well, you are the person who has to experiment say well, tell me what is the size of the cyclist, what is the speed? There is wind, this is a vector. So, it has got magnitude and direction do you want it on a road or a dirt road condition.

So, let us do is it to be on a level ground or upgrades and downgrades. So, these are the question that somebody would pose and very genuinely they should be posing this, without that posing a question like this is quite meaningless does not help us. And, now that we start asking all these questions, we suddenly realize this problem has become very complicated.

So, now let us have a look what is it that I really need to know, and why do I need to know it. So, this is what we are doing this is in the D 1 phase now, and we say look I just want to figure out how much energy this person will consume if there is a headwind on it.

So, we are now starting to make the problem little more crisper, by discussing with everybody else who is concerned with this. And so, look I will only look at a smooth road, we will take an adult and that too is a very vague number so, we will have to give some size or requirement on it.

Then we will say look I want to look at 3 4 speeds of the cyclist, I am only going to look at a headwind; that means, a cyclist is there, and the wind is coming on that the cycle is moving in this direction. And, we will only look at 3 wind velocities, we will look at a smooth road and smooth again is thing we will say we get a tar road. And, we say we will look at a level ground and anything else that has to be there and this is what it does.

Where we can also include how many riders are there, you may have a bicycle with just one person with two people with three people. So, you have to say ok, I will only look at a single rider who is cycling and this is what I want to know. So, this is what we are doing in defining the experiment, which is what I said was D 1 and while defining the experiment is so, difficult.

Once we have done this then, we go to the planning phase and say look now, this is my objective, this is what I want, what options do I have and we can say I want to do a that is where we start looking at various concept possibilities. One says I just want a very quick and dirty answer, I do not care about too much of a exactness, I just want to know is this plus minus 10 percent, 20 percent, 30 percent whatever it is.

Somebody says I want to do a very thorough specific work, I will make at least a semblance of a wind tunnel or we will say very rough or a crude device, which is the wind tunnel and there I will measure it, then it has to be a very big size thing. Or we have an option, we said look I do not want to do anything like this, I want really top quality work and say I will go to a proper wind tunnel in which I will put the cyclist and make the measurement. And, then you will realize then of the size of the cyclist is such that the wind tunnel may not be able to accommodate it.

Now, you go into that part of the concept design, where we say look I cannot do a 1 to 1 scale testing, I will have to scale it down. 1 is to 2, to 1 is to 5, 1 is to 10 whatever. And, then you need to be clear about the theory on the basis of which you take data from a scaled experiment and be able to interpret it for the full scale system. So, that is what is giving it is giving us three options, maybe there are more. But, they have time implications, cost implication and of course, the quality of the data that comes.

Then, we say look do I need to make everything and in case I go to the detailed design stage, the implications are different for the three different cases. Here, we may have to design a scaled model then fabricated make it and get done. So, that is D 3, D 4, D 5 all that gets done. In this case we may actually have to make maybe everything, if you do not make a wind tunnel, we may just decide that I will just put a blower in front of the cyclist and see what happens.

So, you would still need some level of design some fabrication and then some checking. In this case we may not do too much of a design, we may just rely on ambient air wherever the velocity is we just measure it and make a setup to do that. So, this is a very light work of D 3 very little of D 4 and almost no D 5. And, then all of them they will come down to the execution phase and finally D 7, D 8, D 9 and complete the experimentation process.

So, this is another example which tells you that just posing the question was firstly a challenge. And, then how do we get the data to answer that question have a very wide range of options before us, which one we will do why we will do that is also our decision. And from that we get data of different quality, different uncertainties and is that good enough for the interpretation that we want. So, those were two case studies, where experimentation helped a lot. They help the experimenter in deciding what to do where to do.

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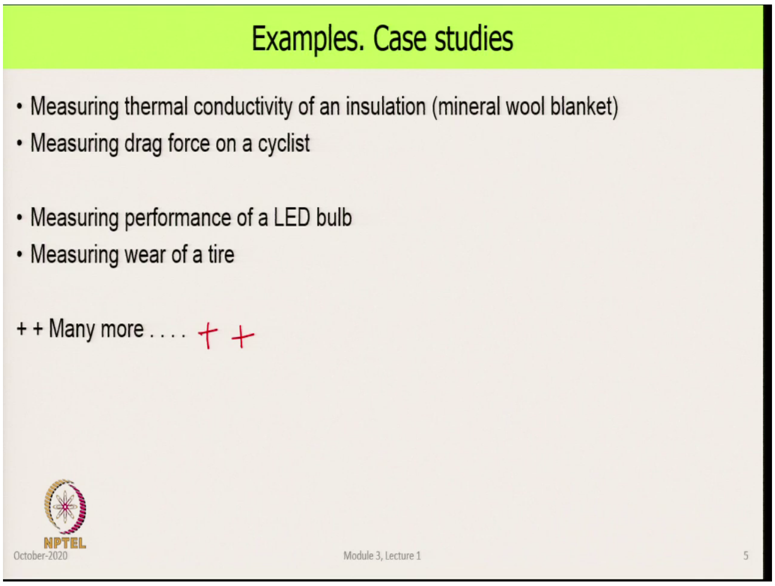

The first example I had given was on thermal conductivity of an insulation material, like a mineral wool blanket and the second was on measuring drag force on a cyclist. These were just two sample examples out of many many many that are possible. For example, we want to measure the performance or the efficiency of an LED bulb that could be our experiment or we want to measure the wear of a vehicle tire.

So, like that we can have a lots of case studies and example. And, in the course of the problems assignments and later in the course, we will look at more and more examples of experimentation and application of uncertainty analysis.

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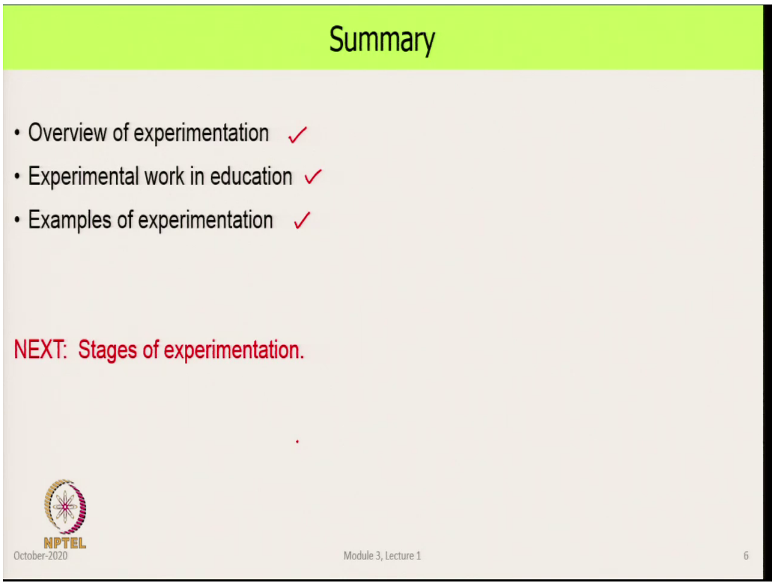

With that we will conclude this first lecture, where we have got an overview of what is experimentation; we saw how experimentation is largely missing in our education. And, I gave a couple of examples of experimentation and its application.

In the next lecture, we will look at the stages of experimentation and go into the details of each stage. With that we conclude this first lecture on experimentation.

Thank you.