Introduction to Uncertainty Analysis and Experimentation
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Lecture - 09
Experimentation stages/phases (II)

Welcome to this course Introduction to Uncertainty Analysis and Experimentation. We are learning about the process of Experimentation this is module 3, and today is lecture number 3 which is a second part of the two series lecture on the Stages and Phases of Experimentation.

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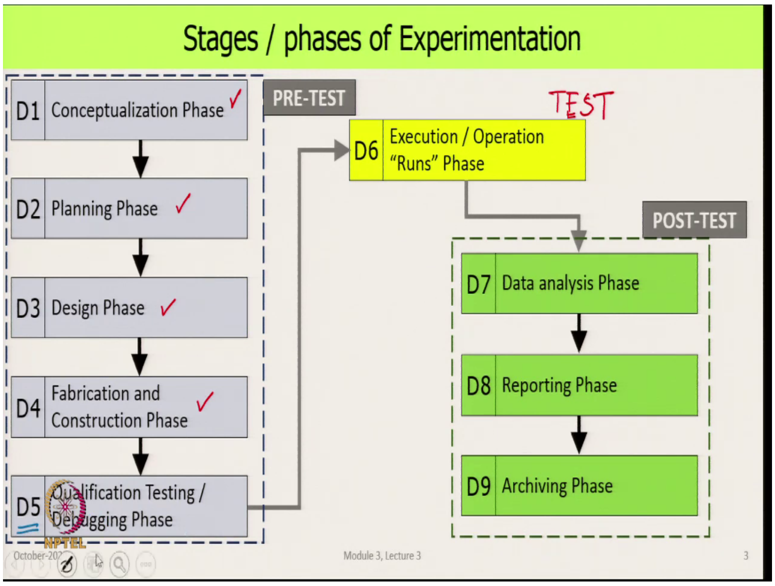

To recap, from the previous lecture, we had identified 9 phases of experimentation. These were conceptualization, planning, design, fabrication and construction, qualification testing and debugging, then execution operation, there followed by data analysis, reporting, and archiving.

We group these phases in two distinct categories. One was all these one, D 1 to D 5, and the other on this side which is D 7 to D 9. And we call these as the pre-test activities or the pre-test phases, and the other one was the post-test phase. By test we meet this operation of doing the experiment, executing the experiment, this is the test part. So, we have pre-test, test, and the post-test phase. With 3 very broad categories experimentation can be divided.

In the previous lecture, we looked at in detail at the conceptualization phase, the planning phase, the design phase, fabrication and construction phase. Now, we will look at the remaining phases and conclude our discussion on experimentation. So, the first thing we take up now is phase D 5 which is qualification testing and debugging.

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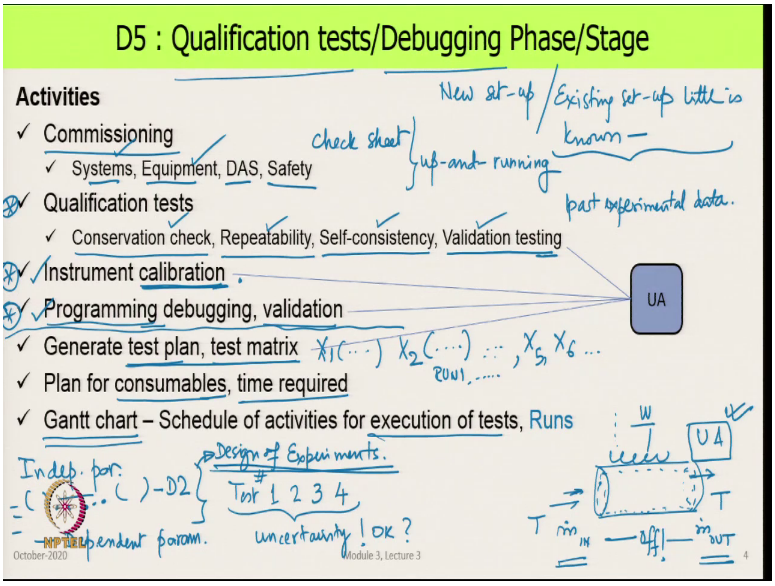

So, this phase is coming at a time when we have completely assembled and got our setup ready and operating. So, we can say that now I have something that works, the question is do I straightaway go and start running experiments and start collecting data. The answer is no.

If you already have a setup that we are using, which has gone through all these checks and balances that we will now talk off, then we are very ready quickly ready to go and start taking data. But if it is a new setup or a setup with which we are not familiar with then we must do qualification tests and debugging.

So, if it is a new setup or we are using an existing setup about which we know very little, then we must do the qualification tests and debugging. When we say existing setup and little is known it means that there could have been somebody else who has done all that work they know everything, but they are not there now any longer or they are they are not ready for it they are not there for advice. So, we do not take anything for granted. So, that is what this part is.

And we say with, I have a setup, I have equipment instruments everything, but I will make sure for myself that everything is as good and thorough as I want it to be. I am not going to rely on what somebody else tells me that is the reason. So, what are the activities in the qualification tests or debugging phase? First is commissioning.

Commissioning means that you are starting something for a first time and you do not know what could happen, there could also have been small slip ups in the assembly process and that could cause surprises when you start operating it. So, here we do step by step, one by one checks if we have a check sheet that would be very helpful.

So, we know beforehand what are things that we should go through and in what sequence, we check out every system, we make sure every equipment is correctly connected and ready to operate we make sure that the data acquisition system which is all the instruments, electronics, computers, they are all connected correctly.

And we are also clear of what safety precautions we have to take while operating this. So, with all that in mind we go one by one, check out one system at a time and make sure that it is doing what it is supposed to do and that is how we get everything up and running. So, at the end of the commissioning process you have everything that is safely operating.

Then, we start a bunch of tests. The first one which we call the qualification tests. Qualification test means that for any setup we know it obeys certain laws of physics, we know that we got some equations for that from certain courses, and we should make sure that the setup that we have made in at least some of the cases is checked against those laws and principles to make sure that it obeys that. So, that is what we do is, here that the first thing we do which is the conservation check.

For example, if you are measuring flow through a pipe and you have measured the velocity at this point and on the outlet we measure the velocity at some point, we may be interested in the velocity, but before we can confidently say what is happening to the velocity, we should be able to convince ourselves from first principles that the mass flow rate of the fluid going IN is equal to mass flow rate of fluid coming OUT.

This sounds very nice in theory that the two are equal, but in the world of experiments when we actually start making measurements and then apply various calculations to it these numbers are bound to be off. And that is where uncertainty analysis comes in. And in light of the uncertainties we have to be able to convince ourselves that there is no statistically significant difference between this number and this number.

Another example of that would be that if this pipe were to electrically heated from the outside, then we know in steady state there has to be energy balance. So, we can take this as a system, apply the first law of thermodynamics to this, and say the energy going IN, and the rate of energy coming OUT, these two have to match. So, we have to measure the heater power how many watts we put in it; measure this and its temperature, outlet temperature and do a calculation and see that the energy gained by water is equal to the heat transferred by the heater.

Anyone could argue that you know this is obvious it has to be true. But in practice it will not be exactly true. There will be some losses say from the back part of the heater to the air, the instruments will have uncertainties, and so again like the mass flow rate getting these 3 quantities to match up with one another you will require uncertainty analysis, and at that certain confidence level you should be able to say that I have energy balance in this device. Those are conservation checks.

The next type of tests that are done is called repeatability. So, it is not that we do the experiment once, get the data, and we are done. We may do that later on when we do experiments, but at least for some cases we will come back maybe the same day, next day or a few days later and repeat everything exactly with what we did in the first time.

So, we do that many times, maybe 3, 4, 5, 10 times, how much it is feasible and what we will see is that the same number that we got in the first test, say test number 1 is not being exactly reproduced in number 2 and neither of them are there exactly in the test number 3 and neither of them are there in number 4. So, at this point we have to say look, this is what I got what is the variability in it, what uncertainty do I get and is this ok, is this what I expected?

At that expectation you would have been a very rough guess because we had not done experiments. The only expectation could have come from somebody else who had done experiments in the past. But this was one important thing as well as this conservation check about which we had no information at the pre-test uncertainty analysis stage. We are getting this data only now.

Then, we do a self-consistency check, and then there is validation testing. And in validation, we have a setup, we are going to do something and we should make sure that what some that some set similar setup by somebody else previously under some parameters has been used and the data is available. So, we try to repeat those various input parameters and see whether result from our rig how well it matches with the result that has already been published. So, we check with what others have done or previous or past experiments.

In a way, we are repeating what somebody else has done and that gives us confidence that what we have planned to do is good, especially when we are comparing ourselves with somebody who did very good experiments. So, this is comes in as validation testing. So, these are the some of the tests that we do to ensure that our setup is doing, what it was expected tool.

The next item I have listed here is instrument calibration. So, before we put the instruments in the setup, we should always calibrate them. So, calibration is the process where we see we give a fixed input to two instruments, one is our instrument and one is a much superior grid calibration grid instrument.

Then, we see what data or output our instrument gives in what data the calibration instrument gives. And then, the comparison of that will tell us how good is our instrument and what corrections we need to make. So, this is a very important part. And there are very extensive literature on the science of calibration, the techniques of calibration, and ultimately what is the best possible result that one gets.

We will come back to this a little later on, where we have primary standards which are the most accurate give the most accurate values of anywhere in the world, then transfer instruments and like that. We never used the top quality instrument which is the standard instrument, simply because it is too expensive and practically not possible.

Every instrument should be calibrated. Some instruments need very frequent calibration. For instance, gas analyzers. If you are measuring the amount of carbon monoxide in the atmosphere, you need to calibrate it every few days. If you are using a pressure transducer or a pressure gauge the recommendation is you must calibrate it every year. If you can calibrate every 6 months even better. So, those are some very important things and this is what establishes what is a very good experiment and what is not so good experiment.

The next item in the qualification testing is program debugging and validation. We have written lot of programs for that setup to collect data, store data, and maybe in real time display data as well. So, what we have to check is that this process is doing its job correctly. We give a specific input, we expect a specific output and we should check whether our program all the data acquisition system of the electronics whether it is doing that or not.

This will also include calculations, say online calculations being done, if there is something off in the formula that gets caught here. If sometimes some wiring is not correct, some reading may not be taken in by the computer, all those things will get checked over here. There may be times where some instrument may have gone bad, you will have to repair it or replace it all of that will get revealed over here.

Once all of that is done, we now say that my instruments are working fine, my program is working fine, every system and every equipment is working fine. I have done all the conservation checks repeatability self-consistency and validation tests. So, now, I am ready to take data. So, that is how long it takes to come to what we have learnt in school and colleges as an apparatus where you just go and take data, it has taken that much amount of effort and time to come to that point.

Having done that we now say that I will generate the test plan or the test matrix which means we have some independent parameters, we say what is the range, over which we will vary these parameters this we got some idea from an earlier design stage D 2. So, so many parameters were there each one of them has a range on which you want to take data and there are some others with the instrument the experiment will give us which we call the dependent parameters.

Now, the question is within this range for each parameter what values will you take for conducting the experiment? Say I want to conduct an experiment from 1 to 10 bar, should I do it that 1, 3, 5, 7, 9, 10 or 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or 1, 5, 10 or 1, 3.5, 7.5, 8.5 and then 10. All of those are entirely possible feasible doable. But then what is the basis on which we should be doing that selection of independent parameters.

That selection process is what is classically known as design of experiments. We are not going into design of experiments in this course. This is an independent course by itself, its extremely valuable and its important lies in the fact that in the example that I gave if the pressure was from 0 to 10 bar and we deduct 1 bar and you got some data we will do the experiment 10 times 10 runs.

But with knowledge of design of experiments and statistics we could have found that we did not need not have done 10 runs, we could have got equally good data and equally good conclusions by taking only 5 readings. At which points that is what the various theory in design of experience will tell us. So, we either use it or by experience we set our own parameters, and then say that parameter number X 1 I will take these, these, these values, parameter X 2 I will take these, these, these values, and from the experiment I will get parameters whatever they are X 5, X 6 and so on.

This tells you that if they said there were two parameters, this side 3 values and this side 4 values we would like to do a minimum of 12 experiments, 12 runs that is how much effort and time is required. If there were 3 that would get multiplied further on. So, pretty soon you will have lots and lots of experiments to do. It takes a lot of time. And the question is could you have got the same learning from the experiment by doing a fewer number of experiments. That is another that is an issue.

But for the time being what we are generating is a table of which X values of independent parameter you should set to do experiments and we call these all the experiment runs, we can call it run number 1 and give some numbering scheme to it. So, that all the data coming from that first experiment is stored in one folder and then you can very clearly trace it later on and look at it.

Once the test plan is done, we know what our experiment we are going to do, if there are how much time it will take. And if there is something being consumed, say a fuel being burned you would know that how much quantity I should plan for, that should I get a 1 month stock or 2 months stock. If I am using some other chemicals how much should I buy; how much should I keep in my inventory, so that I can complete all my runs without interruption at later stage.

We would also know how much total time this whole exercise will take, all the runs. So, it takes you all, 3 months 6 months you have to keep at it. And so, after getting all this we finally, make for our own purpose a timeline of activities which is a schedule of activities in the form of a Gantt chart. We list all the activities on one side and say when they start, how much time they take, and in what sequence they go and that becomes something that gives us a timeline to make our efforts and get the results in that timeframe.

So, these are the main things that happen during the qualification testing phase or we call it the debugging phase. And as you can see, there are a lot of very important things being done in this phase. And how thorough we are in stage D 5 here will innovate determine how good the quality of our experimental data is, how good and experimental we are, that is the point.

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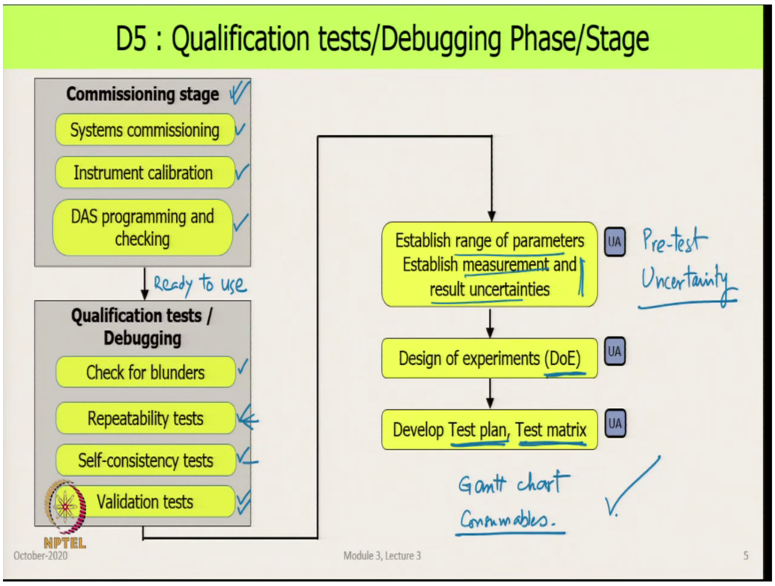

So, here is the sequential listing of the qualification tests. First is the commissioning stage that we saw earlier in which we have systems commissioning, the electrical system, the water system, the data acquisition system, power supply system, all of them are coming and we are checking and making sure everything is ok.

Then, we have the important task of instrument calibration. And third wiring up all the electronics hardware and the instruments and the sensors and the transducers and writing the programs to collect data. And as in many cases these days you can make a mimic on the screen and in real time see what data is coming. So, this is our commissioning stage.

That tells us that the setup is ready to use, which leads us into the qualification tests and debugging exercise where first of course we check for blunders. Some instrument is giving some absolutely ridiculous data, somewhere just say water is leaking, some instrument is not giving any data at all, all these things can be checked. The program is giving absurd numbers or not showing any numbers all those things we have to go back one by one see how the whole system operates, where all it could have gone wrong and then do a bunch of detective work and set it right.

Then, we do the repeatability tests, self-consistency tests, and validation tests. This establishes the repeatability of the experiment which is a very important input to uncertainty analysis. Self-consistency test tells us that look you are ok, you have done your things are working fine.

There is no real gross deviation from what you expect. And then there are validation tests, where we say look the same very similar experiment done by somebody 5 years ago at some other place, gave this data I am repeating exactly the same conditions in my setup and see what data I get. And say that look if the two data output data match then that gives us more confidence that our setup is doing the right thing that is why we do the validation test.

And after that we established the range of parameters on which we will do the experiment. We established the measurement and result uncertainties. This is your pre-test uncertainty calculation. So, this is our link of experimentation by pre-test uncertainty. Then, if we have competence and access to doe techniques design of experiments, we use that to decide what are the values of the parameters for which we will do the experiment, and that helps us to put together the test plan or also called the test matrix.

After that the only thing left is a Gantt chart, and we buy all the consumables. And then while doing the experiments we largely forget what has happened before this time, we look at the test plan, look at the test matrix, keep changing the settings and keep taking data. So, once all of this is done, we have got the test matrix ready, all the material is ready, we are all ok, we get the green signal do the experiment and that is the next phase.

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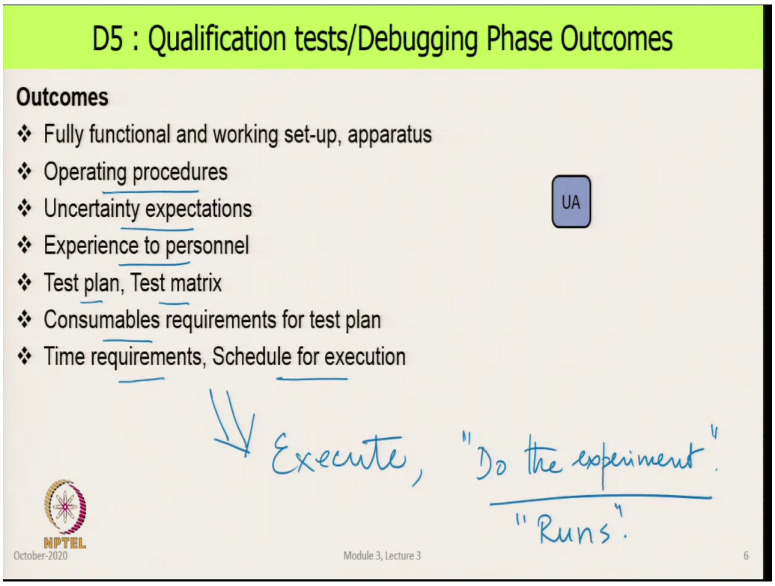

And the outcomes of the qualification testing and debugging phase are here that we have a fully functional and working setup, we have our operation procedures ready, uncertainty expectations have been calculated, we have experience for the personnel to work on the setup, we got the test plan and test matrix, consumables, time requirements and the schedule for execution.

Next step, execute the experiment or as what we have learnt in school and colleges do the experiment or what we will call as execute the runs.

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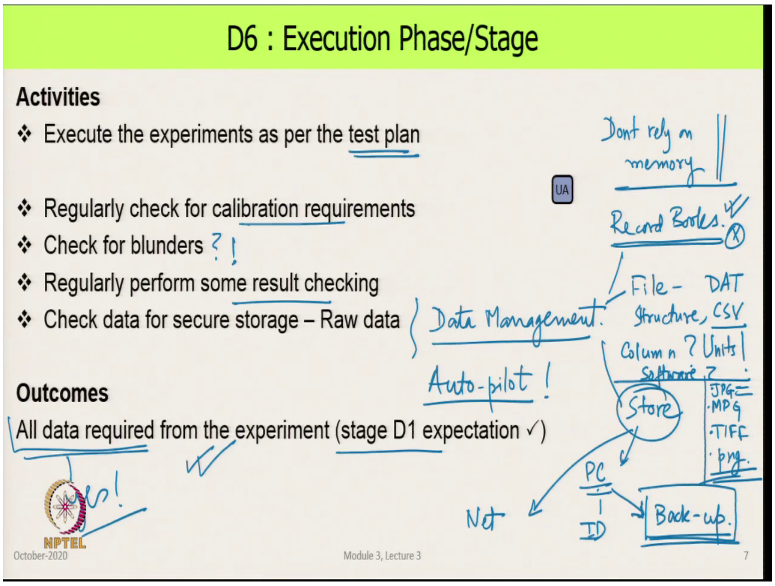

That is D 6 execution phase or execution stage. Not much to write here all the long effort has been done. Now, is the time to just keep executing what our as per the test plan. But while doing it regularly check for calibration requirements. If you have any suspicion calibrate it again or if in the during operation certain device or an instrument starts malfunctioning, if it can be repaired quickly repair it otherwise no option, but to replace it. But all these things that we do we must keep on recording that such and such a thing has been done.

During the experiment just keep looking at the data what is coming and see if some data really looks off; that means, there is a blunder in which case that particular run just write down that things when something has gone very wrong, we will look at it this data is not to be used for analysis. That is the point here.

We regularly as some data starts coming, we start doing some quick calculations on the side and see what is the results look like. Once you got 5 points we can make a plot and see whether the trend something what you expected or it is confirming what others have done, all of that can be done.

Now, what will happen in all these cases is the issue of data management. Couple of decades back or maybe little more all the data was written in lab record books. It is a good practice and I strongly recommend that every experimenters should have a notebook in which they write day to day every day of what happens, what they did.

If something went wrong they should like something went wrong keep it there in the record book because you are two years later when you go back to data analysis and you ask you know what did I do that day, it the only the confirmatory thing that you can get is from your record book. So, this is a thing that I strongly recommend that we should write everything we do in the record book.

If you are going to have an electronic record book on the cloud that is another possibility but keep recording everything you do. The important part is we do not rely on memory. You can be certain that what you did today you may remember tomorrow day after, but if by chance you have to go away and come back after a month, 2 months or 6 months, you will have no idea what we did that earlier time. So, this is a very strong recommendation, do not rely on your memory, record it, write it.

The next is where did the data go. So, if complete all the data was in a hard form it would be on paper in the record book with all the numbers written there. These days you will end up storing it as a file. Then, you should know what is the file structure or if it is in a spreadsheet or if it is a CSV file. The data execution system will put out lots and lots of numbers maybe column wise, but you should know what is in each column, and even more than that its units.

And this when you design the file format it should be recorded in the notebook, so that it is not your memory, sometimes if the file does not have it or gets corrupted or something else happens you are not at a complete loss you know what you are looking at. It will also help you later on after all the experiments are done to go back and look at different days of data taken on different days, and figure out what was going on.

And where do you store it? I mean say file this it also means what is the software with which you can read it. So, it should be clear that it is an open source access what is the thing a CSV file or a DAT file, this can be a bit a lot of things they are open you know that there is no funny thing happening there.

But if there are some other types of files which are proprietary in nature to a particular product unless you have that very product drivers or the products software in future you may not be able to use that at all. This is a real danger. It is not just a data file. These days we have lot of pictures that we take. So, you could have MPEG files or JPEG files or TIFF for images or PNG, all these are things that you should keep track of.

The next thing I was talking about is storage of data. When you take data it may come into a PC or a laptop or a data logger. You should immediately give it some id telling which test it is, what date it is, what conditions this data has been taken in. And then this must be backed up, backup on the cloud or backup on your institutes or college's computer system those are much more safer than your PC. This could get stolen, it could get corrupted, it could be a virus in it, the hard disk may crash, so many things can happen.

Backup data will always be there to a rescue. You can finish the experiment, backup your data, and go to go home, and have a nice sleep. If you do not backup you make it a nightmare as to what is happened to your data. There have been many instances where students have either lost their notebook or the PC got damaged or there was an accident or the laptop got stolen and they lost all their data, months of hard work all gone wrong.

So, this is a very important part these days, data management. And make sure that you are adequately documented each and everything about the file that you have generated about the data that you have generated. Because you will have to come back to it while doing data analysis or maybe even later after 6 months, a year or maybe somebody else will have to come to look at it and re-analyze the data or use that data for their own comparison.

In all those cases you should be able to quickly see which is the file, under what conditions it was taken, what is the format open it up, and take the data and start working with it. So, those are some of the activities of the execution phase. We go one by one keep doing it. If there is a lot of repetitive type of work, yes, it will be boring and a lot of experimental work now is in that sense is boring.

Some of the experiments can actually be on autopilot. In that whatever variables have to be changed, we can have a controller. The control is controlled through your data acquisition system, we just put it on and live it and it keeps on taking data on its own when the parameter has to be changed, it changes the parameter and keep taking data. But in all these things you should regularly go and keep checking that it is doing the right thing because anything here can malfunction.

And if the experiment is on autopilot all the data that you are getting you are not only storing it you could be also seeing it through the net. Today it is entirely possible that you are doing an experiment somewhere and you are physically somewhere far away through the network you can see what is happening in your experiment.

So, after doing all of this the outcome of the execution phase is that all the data that we required which was identified in stage D 1 of the experimentation we have got it. So, we have all the data that is it. Now, we take this data and start making sense out of it and that is what takes us to the next stage.

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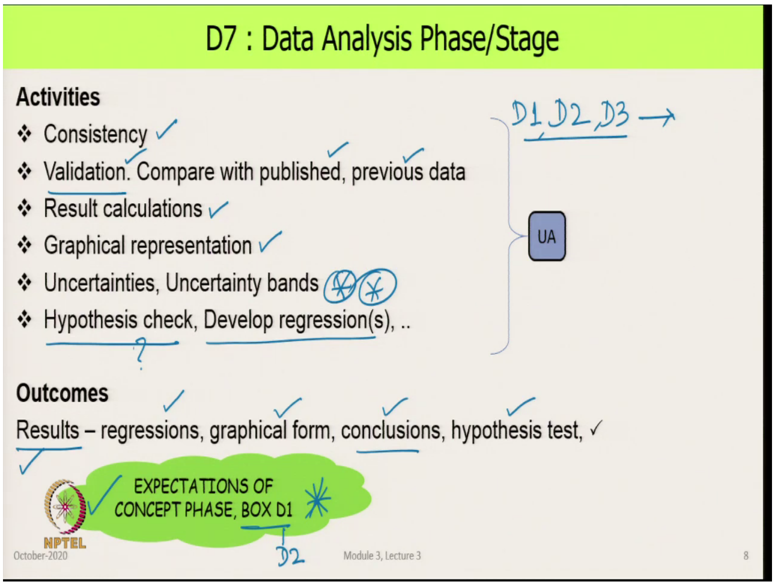

This is the data analysis stage or phase, in this phase we will do what do you want to do with the data as the experimental you are the best person to know, all of that was identified in D 2 and D 3 phases of the experimentation process and possibility 1 also.

So, you know what calculations to do. There is no surprise coming up at this point of time. We check for consistency, validation we have already checked, but you still do a check with the real data that we have got, we compare some of our data with published and previous data. Maybe that may also form a part of the report that you write.

We do all the result calculations and make various plots, all types of graphs, and comparison charts, all of that can be done. We do our extensive analysis of uncertainty analysis and show the uncertainty bands in all our plots and charts. And if in the beginning part we have asked for a particular hypothesis check, we now have all the data against which we can do this check and if need be develop regressions, correlations and all that.

So, here we are working with lots of data and doing various calculations on this. And the outcome of all these data analysis is that we got all the results, in various forms as a regression which means as a equation, graphical form as charts, conclusions as findings which would even give insights into the process. And if there is a hypothesis we even got the answer to the hypothesis test.

So, what we have here as outcomes is basically this part. This was the expectations from the concept phase which was box D 1. So, our loop has got completed. We started with an objective by stating that in box D 1, we quantified it and made it a little more specific in box D 2. Now, that we have done everything that we had to do we have all the data and we are now getting the answer to what we post. That completes the entire gamut of experimentation processes.

We have gone through this entire sequence assuming that you had to make the whole setup and do it. But as we saw in the earlier chart in the beginning if you are using somebody else's apparatus or you are giving data to an outside lab then the design fabrication construction phases are not relevant. But of course, D 7, D 8, these phases are very much relevant.

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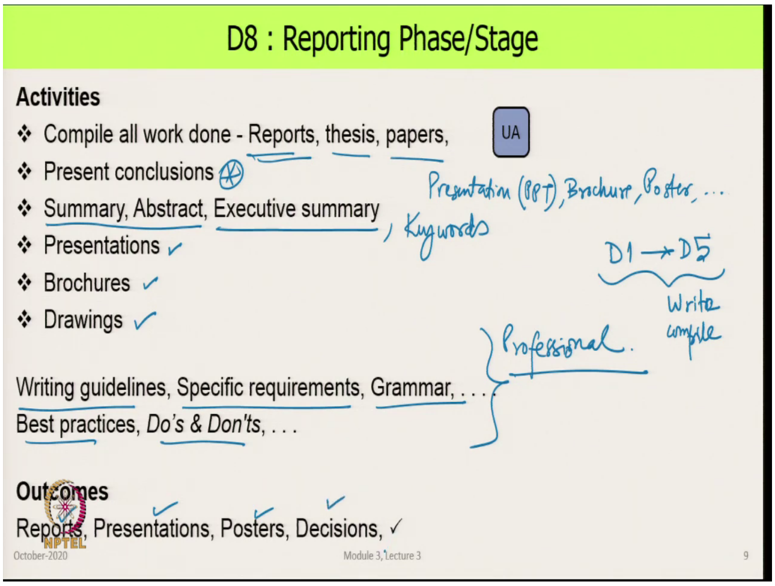

Once you have done the analysis or we are pretty much advanced into analysis, we go into the reporting phase. Reporting phase means we compile everything that we have done in the form of a report or a thesis or a paper or maybe a presentation which could be a PPT type thing or a brochure or a poster anything. And we present everything what we have done, how we have done, all of that is there and of course, the central point be present the conclusions.

Pay particular attention because the most important thing that people will always read in your report is not the whole report, but the summary or the abstract which like one or two pages or a slightly more compact extended one which gives everything a little more detail called the executive summary. And along this word, we should also say what is the key words by which this work can be identified. Then, we can make presentations, brochures, and drawings.

We are not going to go into the detail of some of the things that are there in the reporting phase like writing guidelines, requirements of document, grammar, best practices, dos and do nots, I will not touch these in this course. There are there is a lot of literature which tells you about these things we will follow that and if your organization already has one follow that. So, basically be professional.

You can save a lot of time in the reporting phase, particularly the compilation of data or the report initial part of the report by saying that when you were in phases D 1 to D 6 or D 5, and their experiment was on, all of this which is your experiment design, your test matrix, everything you can start writing it and compiling it.

Because you have everything that you want, you have all the hardware in front of you, you have pictures, you have videos, you have drawings of the setup you can put all that together and everything has to be explained. The idea being that we write all of this for somebody else to read. So, at the end the outcomes are reports presentations, posters, and of course, they are detailing the decisions.

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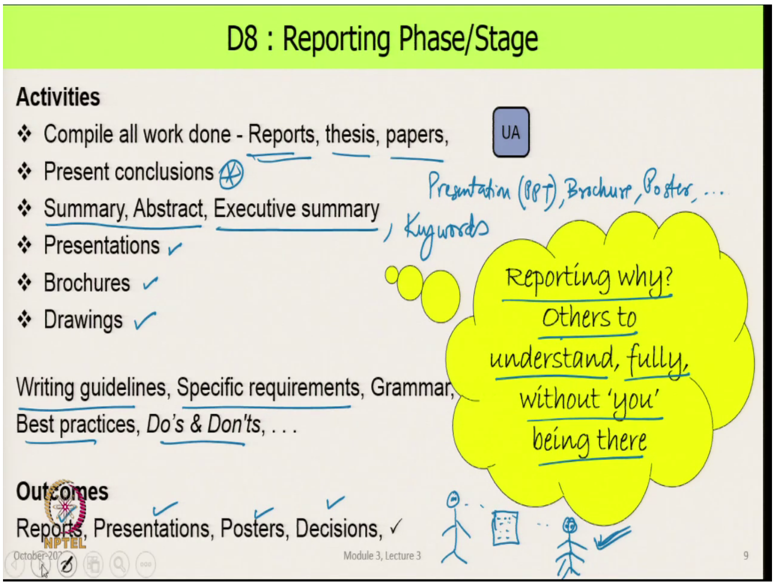

And this phase is very very important. Important because it gets others to know what you have done, no matter what context, whether you are a student in a lab, or a researcher doing experiments or a professional in industry. he communication with somebody else happens why are the report.

So, the two things happening, this is the experimenter and there is someone who is going to read it. And although we can talk do Skype and Zoom, but still in the end what will go is a written document. This gets archived and everybody has access to it, which means that what this person has wants to convey this person should be able to understand it without any ambiguity, without any doubts. The report must be self-standing, completely exhaustive and would not require this person to call up this person and say what does this thing mean. This should not happen.

So, that is the central theme here. Why are we reporting? So, that somebody else should fully understand that somebody else could be today, that somebody else could be somebody after 2 years, somebody else could be you yourself after many years. We write because we want others to understand fully when you are not there. Always keep this in mind.

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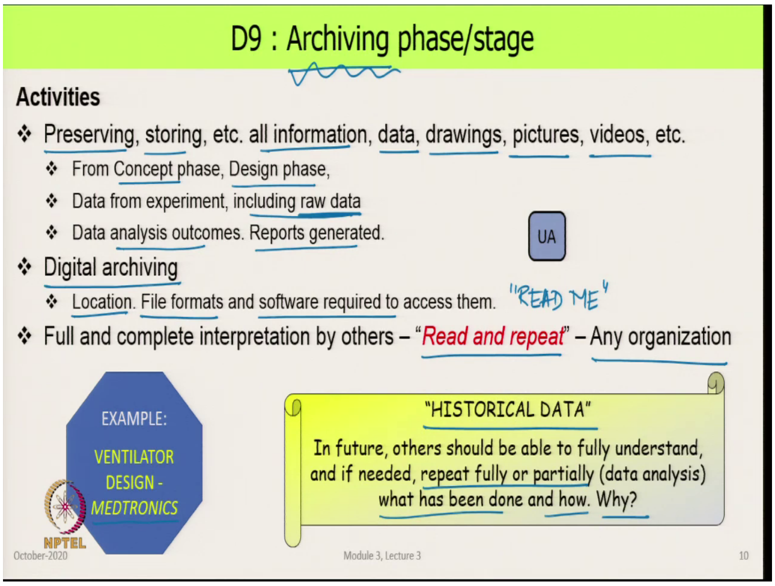

Once the reporting is all done we have only one little thing to do, but that is a very important thing to do which is archiving. This is the archiving phase. Everything we have done this is a lot of effort, lot of experience besides of course, the data and the findings which is useful for future. So, we need to preserve it. The idea is that the next time you want to do something somewhat similar, you should not reinvent the wheel all over again, but take the benefit of what you have already done.

So, we have to preserve and store all information, data, drawings, pictures, videos, everything. Right from concept phase and design phase whatever drawings decisions came everything we should document it and put it. From the experiment what data we got especially raw data which is exactly what the instruments put out all of that has to be are stored and archived.

All the analysis of the data analysis, the outcome of the analysis, all the reports generated, and even data that you analyze, but did not report anywhere everything should be put together and now we got to say how am I going to store it for a long time to come, so that somebody else not known to me can access it and intelligently read it. That brings us to digital archiving.

So, where are we going to locate our storage? What are the file formats, software requirements and always of course, put a small manual which is your read me. We should have everything in so much exhaustive detail that someone not known to you should be able to read and repeat it and completely perform the experiment from scratch by reading the report anywhere that you are there that is the ultimate proof that everything you have done is perfect.

So, data is being looked at in a historical perspective that in future you should be able to fully understand and if needed repeat fully or partially what has been done, how just to make sure that everything was, ok. That is the importance of historical data.

To give you an example from the airline industry the Boeing 747 aircraft was designed in the late 50s, early 60s. The engineers who design the aeroplane are long gone. Many of the aeroplanes made in the 60s, and 70s, and 80s are still flying.

People who are operating them maintaining them is a complete generation which was not born when the plane was designed. And yet when they need a spare part they are able to get exactly the same spare part that was there in the original drawing, for that particular model, for that particular part. All of that is possible because of data archiving and you have a clear way of storing data.

Archiving can generate massive amounts of data and it may be very difficult to appreciate. And a good example of an engineering device where archiving has been done is something very relevant to COVID-19, where in March a company mechatronics a manufacturer of medical electronics instruments.

Considering the gravity of the pandemic took one of its ventilator designs and made each and everything about it public. It is available in open source and this is an real interesting opportunity because no company, no organization will ever tell you each and every little detail of everything in that product.

But here they have made everything public, and I encourage you to go and see these documents and appreciate how much information was there in that one little product is the ventilator. It will also give you a good idea what an engineer design is all about.

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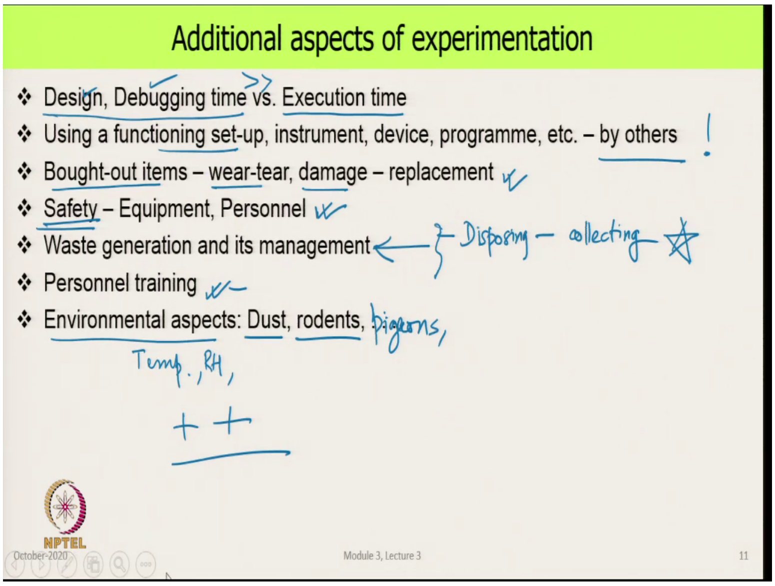

Now, before we end up, a few additional aspects of experimentation. In general, we have done mostly experiments or two hour experiment 3 hour experiment or something like that. Most students have not experienced design, debugging, troubleshooting all of that. Even in postgraduate work or experimental work later in industry, the design debugging time is generally much more than the execution time.

And this is where a lot of hard work, creative work, intellectual work goes in in these phases. When we are using a functioning setup instrument device or program which has been used by others or made by others, we got to be extremely careful we should understand that device thoroughly fully before putting it to use.

Next bought out items there will be some way there will be wear and tear and damage and we may have to replace them. So, we should be clear about that. This is another real world thing.

So, I experiment which is being conducted nicely in the execution phase certainly one thing goes back, well everything stops until you get a replacement and then go ahead. Safety, I have already talked about. This is very very important. Electrical safety, fire safety, injuries, chemical safety, these are very very crucial and we must be professional in handling that.

Something which we have not looked at too much detail we hardly talk about it is waste generation and its management. Many experiments which generate a lot of water may call waste, solid waste, liquid waste, a gaseous waste will go into the atmosphere as pollution.

But there is some waste, first we should have a systematic way of disposing it, but before disposing we must have a proper way of collecting it. Some waste may have harmful chemicals in them, we should be able to find out what is the way to dispose them and safely do that. So, this is important in today's age and time.

Then, many experiments, many setups are people who have were familiar with the setup maybe it is very complex with its very costly and they will largely operate it. For example, the vehicle dynamometer I showed in an earlier lecture that is operated by trained personnel only and so, somebody who is not so familiar with vehicle testing you want to you operate it, they will not let you operate it.

And something typical to Indian conditions, the environmental aspect. Of course, high temperatures is one issue. Many places we have high humidity also. Dust is a major problem. Rodents they can be quite a nuisance. Time and again we have seen experiments going hey wire and you wonder you go there and data it is all looking topsy turvy. And then you start looking what is gone wrong and finally, you will find that a cable has been chewed, so rodent came and chewed it.

Then of course, there is a issue always of pigeons. And you are trying to do some really sophisticated clean type of an experiment in one pigeon by chance gets in, all you are effort suddenly comes to a knot. So, there are many more of these things that you can add to it. All of this is part of the experimentation process.

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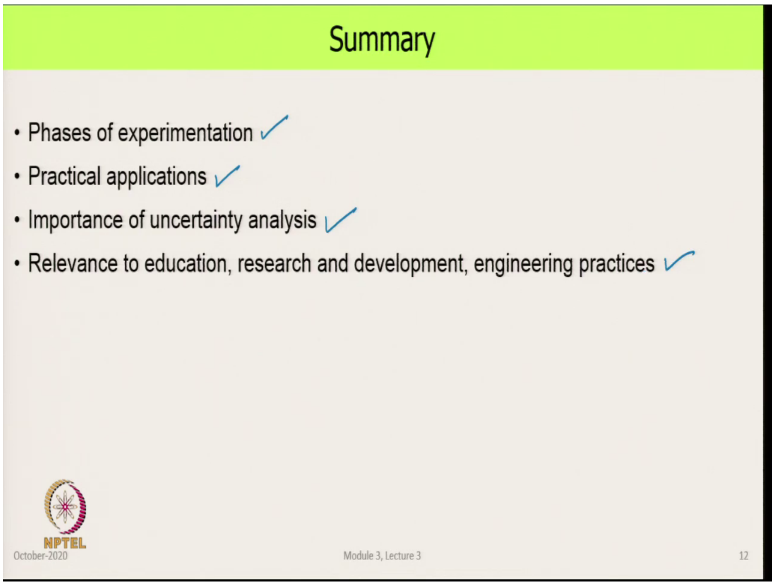

So, on that note we have conclude experimentation lectures. And say that what we have learnt here is all the phases of experimentation, what are their practical applications, how uncertainty analysis is relevant to them, and that is why we went into experimentation in the middle of a uncertainty course, and how they are relevant to education, research and development, and engineering practices.

With that we conclude the lectures on Experimentation.

Thank you.