Introduction to Uncertainty Analysis and Experimentation
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Module - 03
Experimentation
Lecture - 08
Experimentation stages/phases (I)

Welcome to this course Introduction to Uncertainty Analysis and its and Experimentation. We are in the 3rd module on Experimentation and in this lecture, we will look at Experimentation stages and phases which is the first lecture of a two-lecture series.

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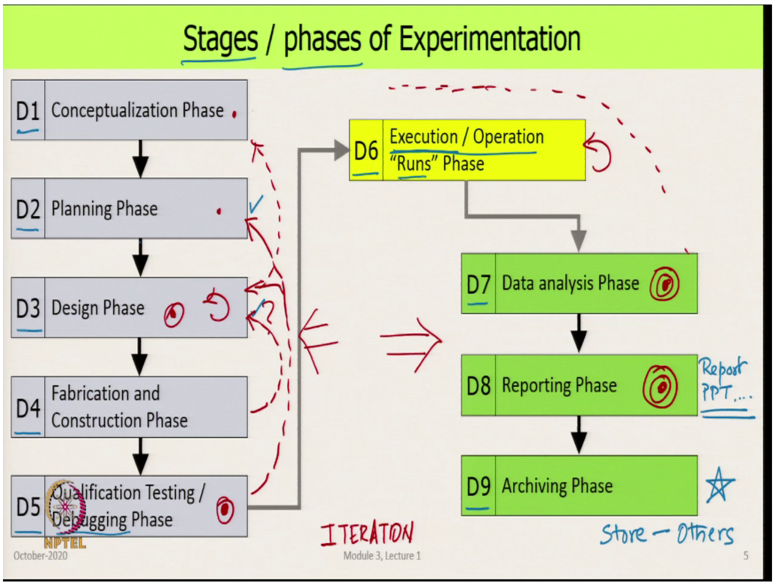

So, those were 2 examples of the process of experimentation. All of this takes a considerable amount of time for discussion. So, in this lecture, we will look at D1, D2, D3 phases and then, in the next lecture, we will look at the rest of them.

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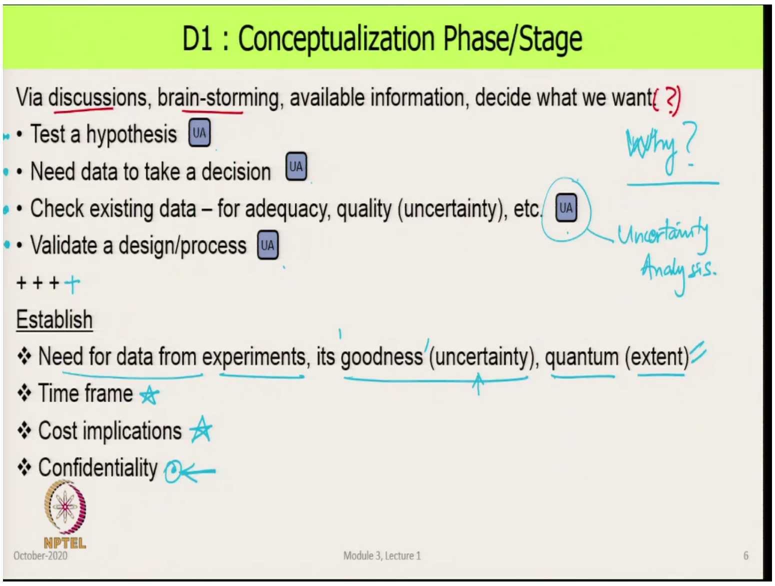

We start with the conceptualization phase and here, what we essentially have done is that we sit in a team, a lot of discussions, brainstorming, look at available information, ask the question well, what is it that we are actually wanting? So, we are pausing the question, and this could take different forms.

It could end up, the question may end up being a question on a test of hypothesis that is this one or it would just be that I need some data or we have some data and we want to check the goodness of that data or we want to build up on that data so that is checking of existing data or we want to validate a design or a process or maybe we had a theoretical design and now we want to do an experiment to validate how good that theoretical calculation was. So, these are some of the possible options.

And you can add more to this as to what form the question or what we may call the objective may take. We are not doing too much into a sort of detailed numbers at this point, but asking very broad questions based on what is it that we want this for rather we are asking you know why am I doing this whole thing in the first place that is the question.

And you can see this little sign that I have put here, here, here, here and here. This sign tells you that at this stage, do we need uncertainty analysis. So, it we are not at this point saying how detailed and exhaustive and thorough the uncertainty analysis is, we are saying that look, do I need to have some idea of uncertainty before I take these decisions? And the answering this for a objective that I have cited is yes.

If I have to test an hypothesis, I must have some idea. That if I have something today and I am making a modification of something, what is the improvement that I am expecting? If I expect a 5 percent improvement is I am uncertainty in the measurement much finer than 5 percent if so, then only I can say yes or no to the test. If the uncertainty itself was plus minus 10 percent or 20 percent, it may be quite meaningless to say that I want to test this hypothesis when the uncertainty in the measurement itself is very large, we may not be able to do the experiment.

So, these are the type of questions that are put together and people who would discuss and all of these as I showed in that earlier example, need not always be scientists and engineers, these could say that like in the first example in the marketing chaps, there might be some manufacturing people in that so, they all are getting together and putting their ideas and coming to this sort of a formation of the question.

So, at the end of this discussions, we established that yes, I need data and I have to get it from an experiment and this data must have a certain goodness which we quantify by the uncertainty and we also get some ideas how much data do I want, and that is what I am saying the quantum or the extent of data. We get some idea say ok, do one experiment or go do three experiments something like that and that is what this part is.

And then, in the practical world, we always have a time constraint say in this much time, I want this data answer to these questions. In many cases, there is a cost implication that we have a limited budget which is always the case, what is doable in the type of funds that we have, if we do not have funds we may have to completely bang on the idea, happens quite often.

And of course, in the practical world, there is the issue of confidentiality. Lot of this data that is generated is very vital input to major design decisions, manufacturing decisions, marketing decisions and so its confidentiality is always an issue. So, just doing an experiment was not about data, but also managing the data very carefully.

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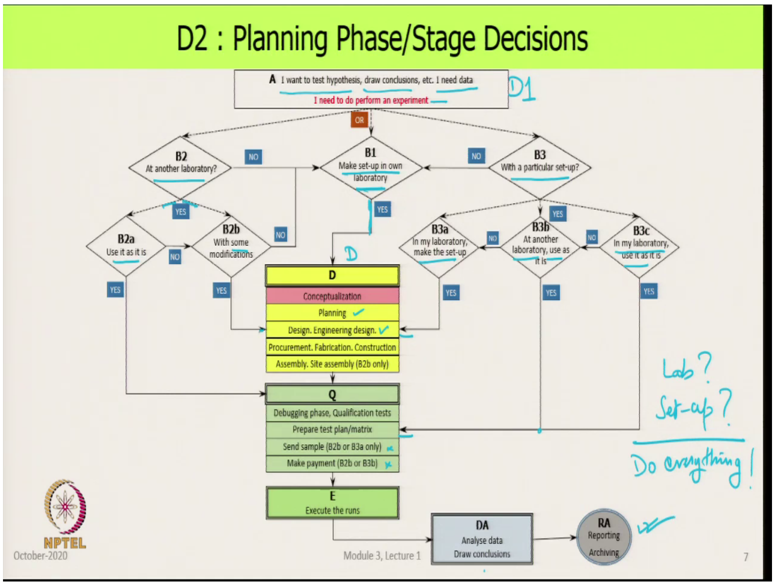

That done, we come to the next phase, which is the D2 phase, the design phase and here is a diagram which captures some of the issues that I mentioned in those two examples. So, we will go over this now. We start the top where we say that look, I want to test an hypothesis or I want to draw a conclusions or for which I need data and I need to perform an experiment. So, this is what came out of D1 phase.

We said now how do I proceed? So, we have three options here. We can either go to another laboratory or make the setup in our own laboratory and we may have other constraints whether we need a particular setup at all or we can make any from a blue-sky design, I can make any particular setup that I want. So, two things happen here.

If you have to go to another laboratory like in that first example that I gave, then we have two possibilities; the answer could be yes or no. If the answer is yes, we come into these two sides and we say well, can I use the setup as it is? So, if it is a standard setup as per the standard, then of course, we will say yes, in which case we are saying now, go ahead and straight away come here maybe do the debugging, but then make the test plan, send the sample, make the payment and execute. So, we skip some of these stages.

If the answer is yes that I can do it in that lab, but I need some modifications. So, this would be the case of that wind tunnel where you want to put something, were we need to make a slight modification to the existing wind tunnel and said well ok, I can make the modification and they are with it. So, we go ahead into the design phase, but not a full blown detail design that is there so, we come here, then from there we have to make it so, there is procurement, fabrication and assembly and then, we proceed to all the other activities debugging, then we keep get our sample done in the setup, execute, data analyze and reporting.

So, if we cannot use as it is and it is not possible to make some modifications to that setup in that lab or if the lab was not available, we have to make it in our own lab. So, we come to box B1. The other way we could come to this and say look I have to make this thing in my own lab, is that we say look do I need to have a particular setup? If the answer is no, then we can make it, we have to make it in our own lab. If it is yes, then we have to see where is that setup available.

So, if the setup is required say a particular standard, then we say look I can do it in my laboratory and make it myself or we go to another laboratory and use it as it is over there, or we already have it in my lab and I just have to use it do nothing more than that. So, the implications of these three are as follows: if we have to do the use of particular setup by making it in our own lab, then we have to make it so, we come to the design part and then, we follow the rest of the process.

If we have a setup which is already there at a another lab and we have to just use it as it is, we just come to the debugging and qualification test where we make the test plan and continue from there. What if we already have the setup in our own lab and we can use it as it is, then also the outcome is the same as this one, we come, prepare the test plan as to what experiments we have to do and then execute the experiments, analyze the data.

So, in both these options, we are skipping some of the stages. So, this is the real option that is there in front of you in the experimentation process. If you have to make everything in your own lab and no particular setup is required, then we are and at this point which means that I cannot go to another lab, I need I do not have any particular setup that I have to make, I have to design everything from first principles, then we come here to the detailed design phase.

And this becomes D3 and then from there we do full, planning, detailed engineering design, procurement, assembly, debugging, prepare the test plan, send do not send the sample, we have the sample with us, we do not need to make any payment, execute the runs, analyze the data and draw the conclusions. So, this is what the planning phase decisions are.

In many cases, we may go with the root of another lab or which setup and there will be few cases where we have to do everything. So, the process of experimentation, the nine blocks that we have seen depending on what this combination is we skip some of them, but in the end, we get what we want so, that is ok. So, that is the planning phase.

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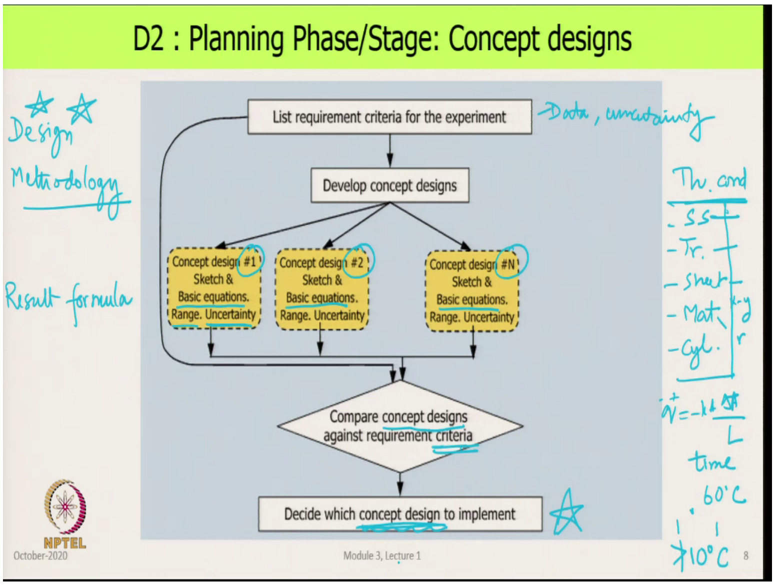

And if we have to make it ourselves, then we come to the concept designs part of the planning phase which is basically like a typical design process. By design, we mean say industrial design in that sense not designing by solving equations. So, what we do is we list the requirement criteria for the experiment which is what data we need and its uncertainty and we say what is the concepts on which I can make this.

To give an example, before looking at that issue of thermal conductivity of a material, there are many possible designs one could be a steady state, other could be a transient, one could require a very thin sheet, one could require a sort of a thicker mat, one could be cylindrical and different type of parameters could be measured in any of these experiments. So, just thermal conductivity itself gives us lots of possibilities to actually get to the answer that we want.

Which one to use? It is our choice. Are they are any of these inherently wrong? The answer is no, in the design process, nothing becomes inherently wrong or incorrect, it is just that they are different, they are different ways of doing it, they all have little merits and demerits of their own, we have to wait those merits, demerits and take a decision on that.

So, we make concept designs like we would do in design. These are free hand sketches, put the idea where we put instruments, what we will measure and write the basic equation. Different number of concept designs; concept design number 1, concept design number 2, concept design number N. As the more the merrier so, then we are clear that we have thought about everything possible and come to a conclusion based on a very wise thinking, the basic equations could be different.

For example, in this thermal conductivity case, this could be the straight equation that q dot is equal to minus k A delta T by L. In the transient case, we will have a time issue coming in. In some of these, the equation would be in x-y coordinates; in this case, in radial coordinates, r cylindrical polar coordinates. So, like this things could be different and those basic equations will change.

We write those basic equations so, that tells us that to calculate the result from the basic measurements, what is our result formula? That is an important very important piece of information for everything else we do later on and then, we decide how, what the range and uncertainty is.

To give an example, in this thermal conductivity thing, when they said that go as per the standard, one of the standard says that you should measure the thermal conductivity at a particular temperature say 60 degree Celsius and in the test, the variation of temperature of the material must not exceed 10 degree Celsius.

So, they have put a very tight restriction and that is going to confine and constrain our designs and the same time, we will also have to make sure that it meets the uncertainty requirements.

So, we do all of that and then, we do a comparison of concept designs and this is again exactly the same methodology that a design engineer would make.

There are different methods of analyzing alternate designs, we could use any of them from the design methodology, look at merits demerits and in that criteria for designing, we could also include our own practical constraints; space, time, money all of that could be factored in and with all of that we will finally, converge on which concept design we are going to implement.

This is a good solid major decision we have taken. Once we have done it, there is no looking back we go forward as we going to stages D3, D4, D5 we are now going into the execution phase, but we now know why we are making this particular design, what the reasons behind it.

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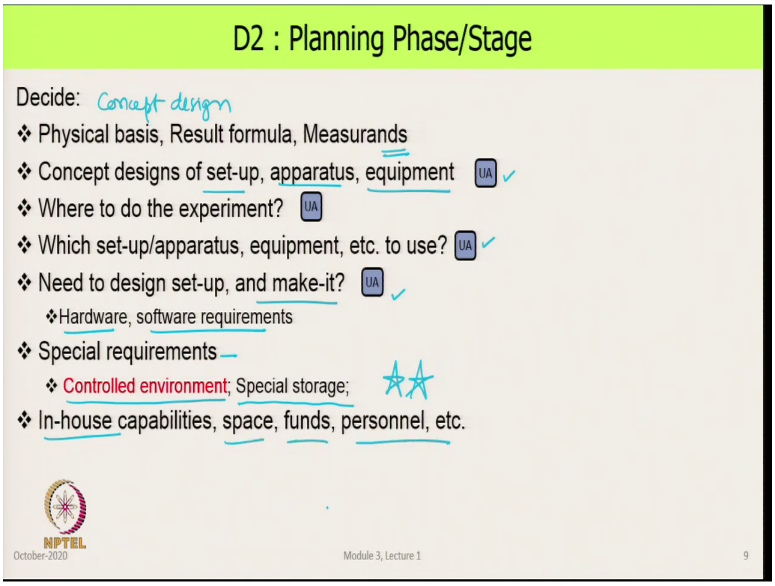

So, at the end of the planning phase, we have with us a physical basis of what to design, a concept design we have which also gave us the physical basis, the result formula and what is the measurands, what will be measure in the experiment that is what this one is. It gave us some idea of the setup, apparatus and equipment and some idea of the uncertainties that we can expect in that.

It also gives an idea where we are going to put up the experiment that also we have decided in this phase, do we have the space? Which setup we will use? If there is already something which is there with us or how we are going to integrate it into the design? That also came up, the need to design a setup that also gets decided at this point and why and how to make it?

This also; this means that we have to take a decision on hardware which is the non-electrical hardware and the electrical hardware and also all the software requirements. So, we get an idea that look this is the thing that I have to do, we are not sitting to solve it at this point, we are not writing any code or buying anything, but we are saying you know to make this thing happen, I have to think through what all I have to do that is what we are doing here and in this cases, we have some idea of using uncertainty analysis.

An important consideration at this point is special requirements of which I have listed, one here which is controlled environment. In many experiments, many setups, you would this is a very very important criteria. We say that I want the temperature in the laboratory to be within plus minus 2 degree Celsius, I want a dust free environment, these are real issues that we face and that complicates the setup quite a bit. There might be issues of special storage say may be a biological material or something which is at very low temperature or something which is very flammable or poisonous we need to have take care of that.

And at this stage, once we have done this, we also say well what are my in-house capabilities, what can I do, what can others do for me. Space requirements, fund, people all of that also got quantified. So, it gave us a lot of clarity on how we are going to go forward and with what constraints that is the outcome of the D2 planning phase which leads us into the detailed design phase, the design engineering phase.

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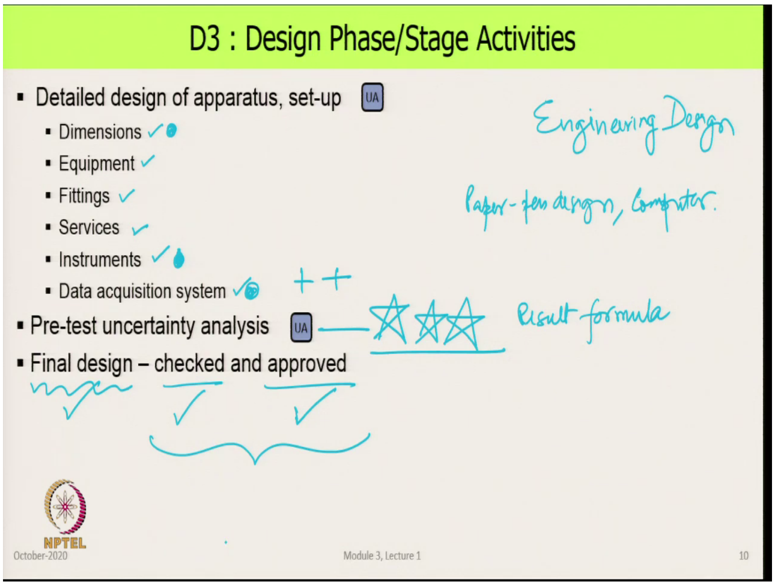

So, in this sense, what was designed there this is now detailed engineering design and now, we are actually sitting with that formula equation that we had, we got lot more knowledge about the practical part of it, we are going about designing everything which includes its design, what equipment's we are going to have, what are the fittings, what are the services like compressed air or cooling water that we may need, instruments that we will put and what sort of a data acquisition system we will have and whatever else that we need to do.

All of these is now we could make a model entirely possible, but by and large, this is a paper pencil or a computer model. So, we can say this is a paper-pencil design; paper-pen design or its design on a computer. We have lot of software where you can completely design it in full detail down to the last millimeter, make see how they assemble, how they would disassemble, what can fit, what cannot fit everything is done. So, it gives us all these things get decided.

And we also do a very important thing which is pre-test uncertainty analysis. We now have an idea of what instruments we are going to be using here, what is the dimensions of various things, data acquisition information we have, we can use this with the result formula that is already there with us and see what is it that the uncertainty will be if you go ahead with this design.

If it is acceptable, we see well, can I reduce the cost? If it is not acceptable, then we say well what are these things can I change so that my expected uncertainty is within what I want; so, that is a quite a bit of effort there and after doing all of that, we have with us a final design which has been checked by somebody else and approved by somebody else.

Professional engineering this is always done and it is a good practice because someone who designed after a while the mind becomes bit saturated, we cannot catch our own mistakes, somebody else looks at it, says that everything is ok, somebody else is fine go ahead, make it, then we are doubly sure that the probability of making a big mistake or something going very seriously wrong is considerably minimized.

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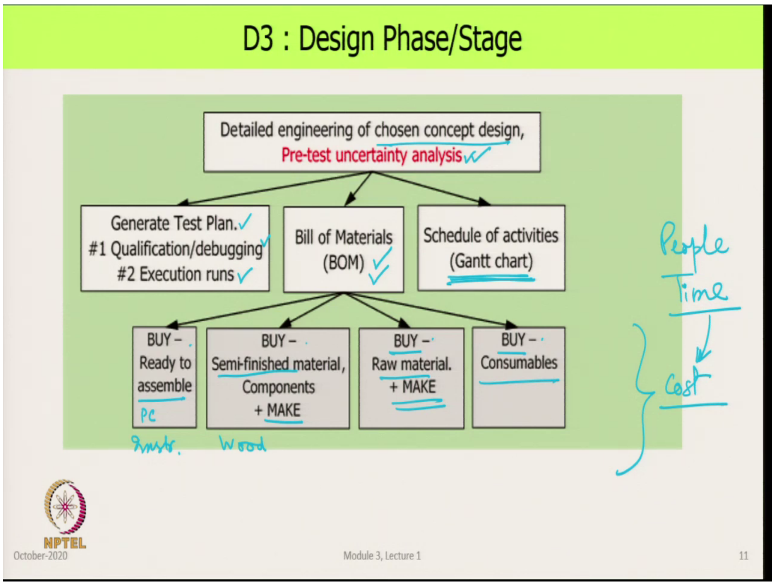

So, these are the activities in the design phase. We do detail engineering of the chosen concept design, pre-test uncertainty analysis we do and once we do that, we come out with the output which is we generate a test plan which includes qualification and debugging tests and how many times we will execute the experiment and with what parameters. So, this gets finalized.

We come up with a detailed bill of materials which includes items that we will just buy and assemble, this could be an instrument or we could buy semi-finished material and make it, this could be like we got something or we gave it to somebody else and said make this instead we have this thing.

And I will modify it and slightly and give it to you or we buy the raw material and completely make the certain that part or system or subsystem from scratch and the fourth thing is consumables. So, this could be chemicals, other materials things will get consumed means they are just no longer usable once they have been used once that will be thrown away.

So, this is what the bill of materials gives us. This is the physical real-world thing that is there and say for instance, ready to assemble, this may include a PC, some instruments. Semi-finished material, this could may be say pieces of wood which we will cut and shape and put it together or pipes and tubes things like that. So, this is an important thing that came out of this exercise, the bill of materials and all of this is also a very good indicator of what the thing will cost.

And then, we come up with one more thing that going forward from this point what is the schedule of activities that if you have to buy these items, some will come in a few days, some will come after a few weeks, some may have a lead time of 6 months, something may take one year to come.

So, how are we going to plan and schedule all these activities? We make an activity chart which is called the Gantt chart and see what is the total time and the schedule at which different things have to happen. It will also tell you at different times when, how much money has to be spent. It also tells you who are the people involved. So, the design phase gives us in much more detail right down to the little nitty gritty details of how this whole thing has to work out.

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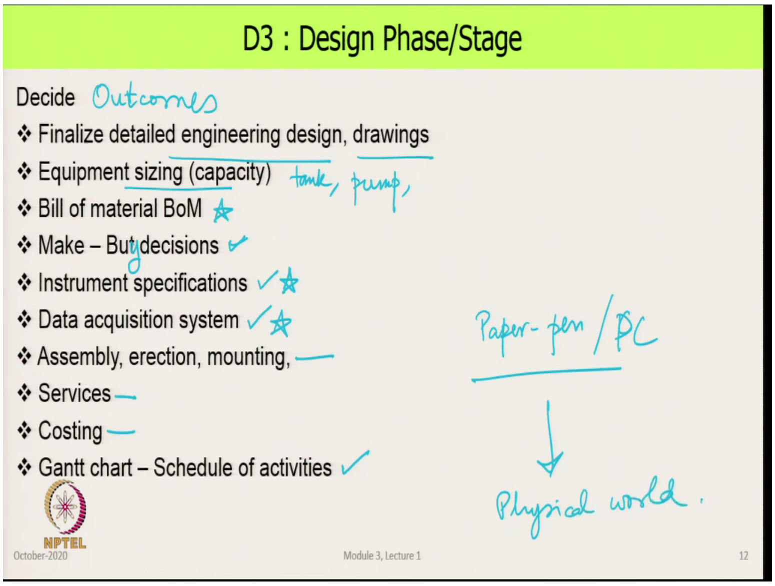

So, the outcomes of the design phase or at the end of it, what do we decide of detailed engineering design with all drawings. We have sized all the equipment like if we had a tank in which we are going to store something we have that. If you are going to use a pump, we know well what is the capacity of the pump or the blower that we want. We have a complete bill of materials from which we have also taken decision which is what I will make and what I will buy.

Instrument specifications, this is the heart of it, what is it that we are going to measure. The data equation system, again this is the heart of our experiment of data collection. It also gives us a complete method for assembly, erection and mounting, how we will put everything together, what services we need in terms of electricity, power supply, air supply all of that, costing and the schedule of activities.

So, we are pretty much ready to go ahead and do it now. Until now, a very little by way of any physical thing from this, this has only been a paper-pen design, paper-computer design; now, we move to the physical world.

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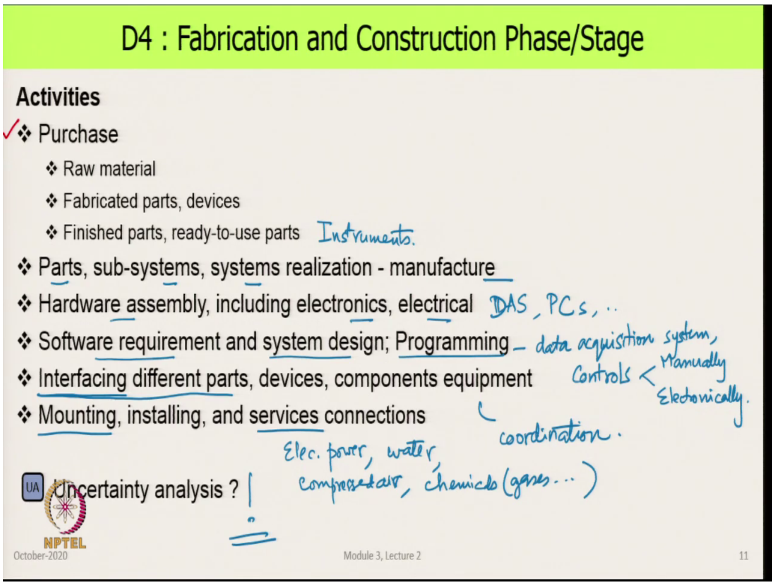

Next, we will look at the fourth stage of experimentation which is fabrication and construction phase. So, at this point, we have the complete detailed engineering design ready, we have the bill of materials, we know what to buy, we know what to make, we know where we will do it and now, we go to the point of actually making it happen.

So, the activities of the fabrication and construction phase are first is the purchase, purchase of raw material, fabricated parts, semi-finished parts, devices and ready to use parts and this includes; and this includes instruments, then we go ahead and decide what has to be made.

So, some parts, some systems and some systems we are getting into the realization mode which is manufacture or and assemble with different components together.

This includes hardware assembly, including electronics, electrical connections and connections to data acquisition systems and PCs. The software data collection requires a program to run it and control it. So, we have to develop the software requirement as to what it is supposed to do, and we come out with a system design document for the electronics.

With these, we are ready to do the programming of the entire data acquisition system. This could also include some controls which may be done either manually and also electronically. The next having got all the things together, the next big challenge is interfacing different parts, devices and components together.

The keyword here is interfacing where we have to make sure that a part which has come either as a bought-out part which we are ready to use or a part which we have made or a part which is half and half of that, all of them have to harmoniously fix together and talk to each other. This calls for a lot of coordination.

And then comes the idea of mounting, installing and making the service connections. The mounting includes where we will put it, whether it has a frame, whether it has a foundation, where it sits on the floor, what are the services that it requires every setup will of course, require electric power could be of different types.

We may need UPS power for something, we may need three-phase power for something else, we may need water, flowing water requirement or just a makeup water requirement, a flowing water will be required if something is cooled by water and then, it might have a need for say compressed air or in many analytical type of work, we will require various chemicals including gases which are connected through a manifold.

So, we get into the thick of putting all these things together and we get our setup done. So, this is a part where you are making things, there is not that much by way of calculation or solving equations. So, uncertainty analysis has a very minimal role if not any role at all in the fabrication and construction phase.

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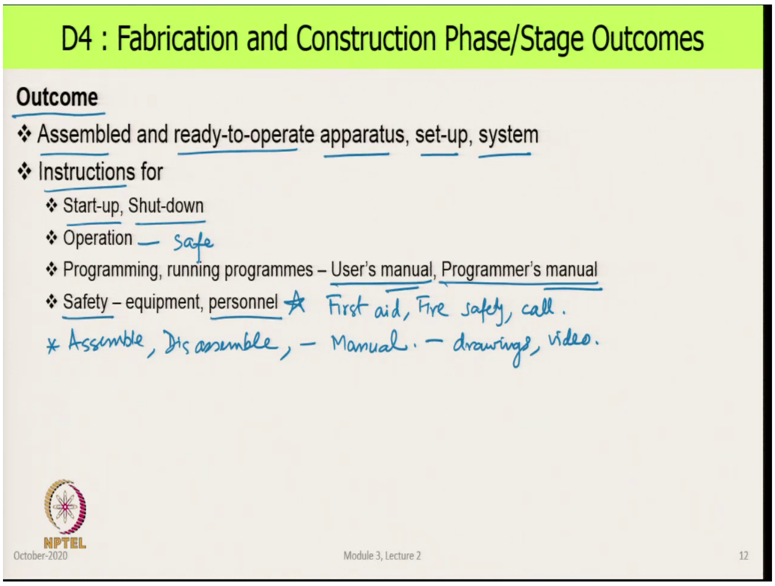

Once we have done all of that, the outcome from this phase is a setup or an apparatus or a system whichever way you like to call it which is fully assembled and ready to be operated. So, we can start it and make things happen.

We also have put it together and in the process of putting together, I have also realized how to assemble it, this will also tell us how to disassemble it and this is important because if in the course of the experiment some part has to be changed or some part breaks, then we will have to make part or full disassembly, replace the part and then, assemble it all again. So, that is what we do.

So, this requires a complete manual of how to do things that means, we have documented step by step how to put it together, how to take it apart preferably with lots of drawings and these days, why we were assembling it, we could also make videos so, that gives the user an idea of how this original thing was actually put. We also put together instructions for startup and shutdown.

So, what is the sequence in which we start things? First what do we do? Next what do we do? Next what do we do? And then, we get it fully running, then how we take data and then, how we shut it down. Then, there are instructions for operation including safe operation do's and don'ts and then, there is a whole bunch of documentation on how to use the data acquisition program and make the control program and how the programs have been written that if the software data acquisition program has to be changed somebody should be able to read it, understand it and make changes to it.

So, there are two manuals coming up depending on the complexity of the experiment, we could make a very extensive manual, or we could just make a sheet with an itemized things to do and that becomes our users-manual or programmers manual and last, but not the least, safety.

Safety of the people, safety of the equipment this is absolutely of topmost importance. Safety does not happen by chance, we have to think through it, we have to plan for it so that it is as safe as possible and still be able to foresee that if things go wrong, what should be a response.

So, if there is a possibility of injury, we must have a first aid box, then fire safety and in case of an emergency, we should know whom to call. So, even if you know nothing about it, at least make a call, the right people will come to your help.

This is all very important in the end, equipment may be destroyed, but human life is too precious, and we must protect it with all the things that we can do. So, this is the outcome of the fabrication and construction phase. We have an apparatus for equipment fully assembled with everything there now, it is ready to operate.

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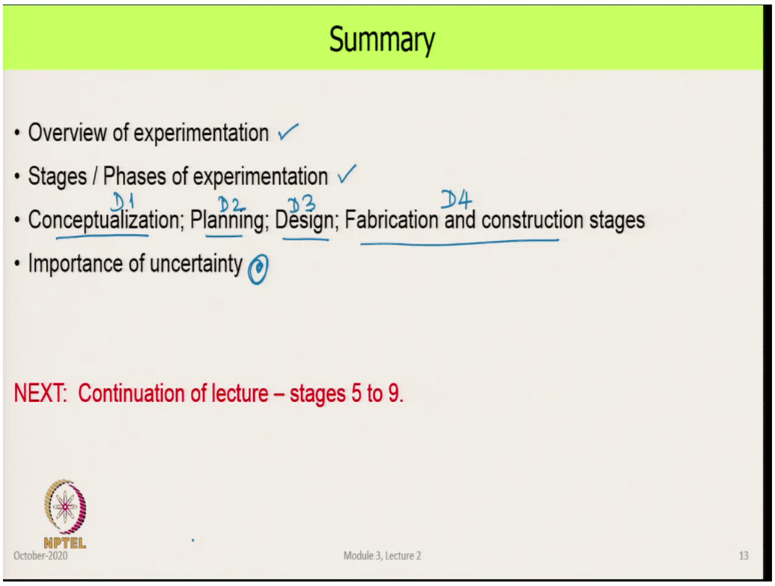

On that note, we will conclude this lecture here and continue in the next lecture. In this lecture, we have had an overview of experimentation where we looked at what are the different stages and phases of experimentation, how they go in a sequence and how there is iteration between phases and within a phase.

Conceptualization phase, planning phase, design phase so, these were the phases that we have looked at in detail now. Four phases that we have we call these D1 conceptualization phase, planning D2, design D3, fabrication and construction D4 and in each phase, we knew what we started with, what we ended with. We were very clear, distinct outcomes for each phase that we have; and in doing so, while we saw what was being done in each phase, we also saw what was the importance of uncertainty in those phases.

So, we will conclude this lecture here and continue with stages 5 to 9 in the next lecture. So, that concludes our 2nd lecture in the module on Experimentation.

Thank you.