Effective Engineering "Teaching" in Practice
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Lecture - 09
Effective Laboratory Courses

Welcome back. We have progressed quite a bit in this course on Effective Engineering "Teaching" in Practice. This is given in collaboration with the Teaching Learning Center of IIT Madras. I thought I'll briefly review what we have done so far before we get into the next topic. We initially looked at an inexperienced engineering teacher's view. How the teacher would view it typically and so on so forth.

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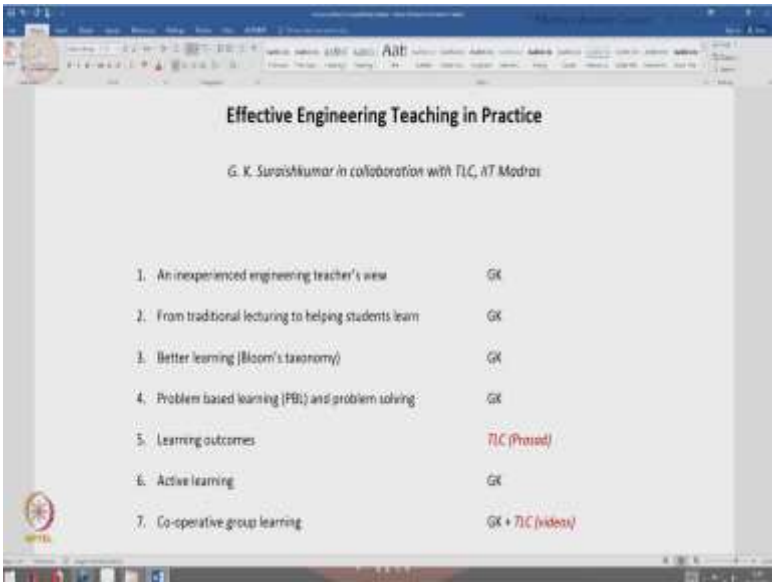

Of course, this does not apply to you if you are skilled and you have a natural flair for teaching and so on, but typically what the inexperienced engineering teacher goes through was what was covered in that particular lecture. And then we saw how to go from the traditional lecturing - I talk you listen to helping students learn, the lecture is quite a strong base to have as long as you realize that a lecture is just not I talk you listen. And then we looked at how we could understand better learning itself.

We used Bloom's taxonomy which is the most popular taxonomy around there are other taxonomies, but Bloom's taxonomy is the most popular taxonomy around to understand what better learning is all about. Then we looked at problem based learning which is the

first easiest extension to the lecture that one can make, I think it is an opinion. And then, we also looked at some aspects of problem solving which is necessary for any engineering student. Students need to have the ability to solve problems. And then Dr. Prasad, the Head of TLC, told you about learning outcomes, how you need to be clear about the outcomes of a course and communicate it to the students also so that they are clear.

And then we looked at active learning which is essentially anything that involves the student in the learning process, it encompasses a wide range of aspects and then we looked at cooperative group learning along with some videos and so on and also flipped classroom in the previous lecture, where we saw how the traditional means of learning through lectures is flipped. In a traditional lecture the information is given in the classroom the students go back to their home or hostels and work on it to understand it better. In the flipped classroom the initial exposure is outside the classroom, and then in the classroom the student engagement is improved to improve their understanding and to develop various other skills that are reflective of the deeper levels of learning according to Bloom's taxonomy. This is what we have seen so far.

Now, let us move on to the next thing which is how to have effective lab courses in engineering.

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Laboratory is a very important concept. Unfortunately an oft neglected aspect in engineering but let us see how to make them affect. Effective Lab Courses - we will spend some time on this.

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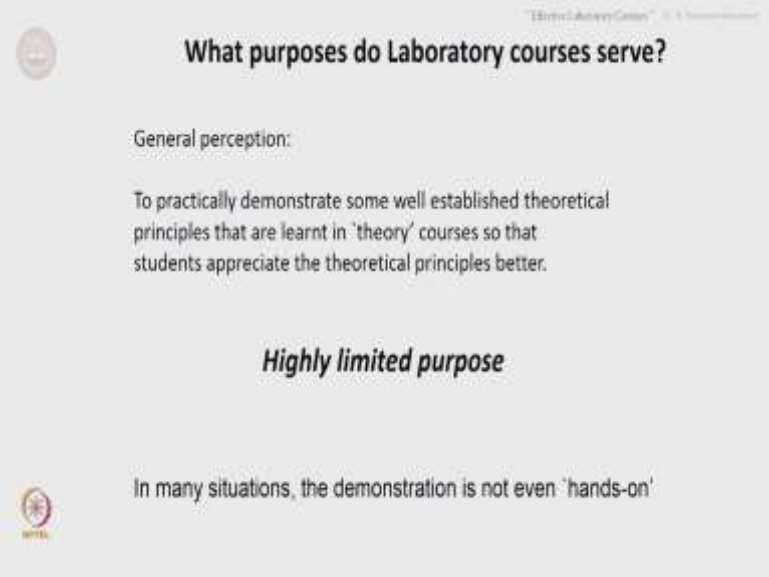

Now when we have something in a curriculum, we need to be clear about its purpose. This takes a while for faculty members to develop. Many faculty members are not aware of what the various parts of the curriculum do to the curriculum itself, that falls in the curricular design, which we are not really covering explicitly in this course which is very important.

Experienced teachers who have actually gone through the process of curriculum development will know the importance of it. I had an opportunity to think about these things and that is when I realized I have not really thought about this earlier when we had to formulate a curriculum for the biological engineering, B.Tech, M.Tech and so on. Then the level of thought that is needed the kind of considerations that are needed opened an entirely new vista to my understanding. So, here that is a different aspect. Now let us look at what purposes do laboratory courses serve in a curriculum, what do they build in students.

The general perception is usually something like this, to practically demonstrate some well-established theoretical principles that are learnt in theory courses so that the students appreciated theoretical principles better, this is the way typically it is seen in

engineering, the way things we have seen when I was a student and so on so forth. At least my perception was that, limited perception was that and so on.

This is a very highly limited purpose of laboratory courses. In many situations, you know the demonstration that we talked about just above is not even hands on. Somebody else a demonstrator or an instructor, themselves, they demonstrate it to the students and therefore, even the feel that the students need to develop for various things of relevance to their profession they do not have, either because of funds limitation earlier, nowadays that is not a major concern, but the laboratory course if it is looked this way and if it is limited to demonstrations by somebody else is very very limited.

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What purposes do laboratory courses actually serve? If you look at your reference book Wankat and Oreovicz, they say the following things about laboratory courses based on literature. So, it is, it has the peer approval and so on so forth evidence base sometimes, they develop experimental skills definitely, they expose the students to some aspects of the real world in a very guided fashion. It is not all theory that they learn in theory courses, there is some aspect where things will not work and so on, that exposure is given to students through lab courses.

It gives them an opportunity to build objects depending on the engineering they are doing, kind of engineering. It leads them onto a path of discovery if well done. It exposes them to equipment that is important for the profession. It can increase motivation

significantly, it improves or actually it demands teamwork and brings in the concept of teamwork in students, which it is a totally different concept by the way. When a set of people are put together, students are also people, when set of people are put together, you are bringing in people with different kinds of mindsets, different kinds of values and so on so forth, some of which, some of whom may not even value teamwork. They may not understand the place for teamwork; teamwork has a place, working alone has a place, where there is a need you need to work in teams and students may not typically understand the value of teamwork. All this is very easily brought in while doing a lab course, it becomes necessary even.

Networking, talking to others and things like that becomes a part of the need here. Communication, the need for appropriate communication, which is highly lacking in engineering students also comes in. Later on we will see some of the basis of this you, know the social communication aspect being missing in students, as to why that happens and so on so forth. Independent learning aspects also come in and there are very many other aspects that can be built as a part of an effective lab course.

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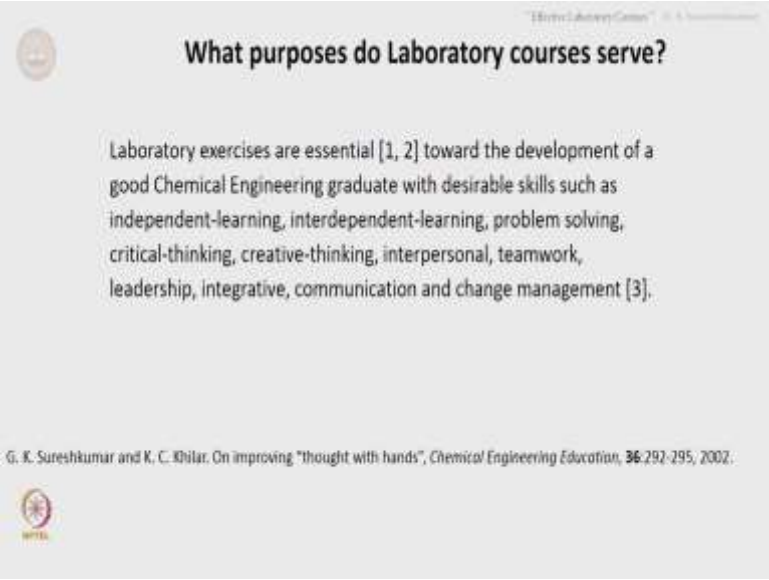

We have published a paper way back in 2002. The title is on improving thought with hands in chemical engineering education and most of this lecture will draw heavily from that paper which is peer accepted. It is a good journal, reputed journal and I will be drawing on this for this particular lecture. So, what purposes do laboratory courses serve

reading from that paper - laboratory exercises are essential toward the development of a good chemical engineering graduate, I am a chemical engineer basically and then I am a biological engineer; now, with desirable skills such as independent learning, interdependent learning, problem solving, critical thinking, creative thinking, interpersonal skill, teamwork skills, leadership skills, integrative skills, communication skills and the ability to manage change. All these are necessary for the student laboratory exercises, laboratory courses are very easy or a very effective means of building these up in students.

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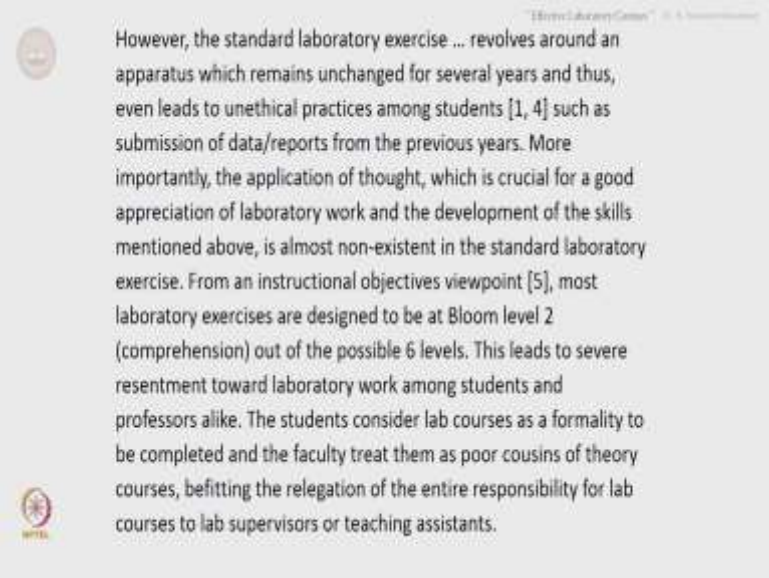

However, the standard laboratory exercise especially in chemical engineering at that time, revolves around an apparatus which remains unchanged for several years and thus even leads to unethical practices among students anywhere in the world. Such as submission of data reports from the previous years and so on. More importantly the application of thought which is crucial for good appreciation of lab work and the development of skills mentioned above, the previous slide is almost nonexistent in the standard laboratory exercise. From an instructional objectives viewpoint, most laboratory exercises are designed to be at Bloom level 2 or comprehension level at best, out of the possible 6 levels. This leads to severe resentment toward lab work among students and professors alike.

The students consider lab courses as a formality to be completed and the faculty treat them as poor cousins of theory courses, befitting the relegation of the entire responsibility for lab courses to lab supervisors or teaching assistants. This used to be the case earlier, probably this is the case in some places now and this is sad.

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Therefore, we design something else. To quote from our laboratory guidance manual that we gave out to students on the first day of classes, before the lab sessions begin. The overall aim of this lab course is to help and inspire students to appreciate the underlying themes of experimental aspects/ approach to engineering or science with fluid flow aspects as the model subject.

So, you see the aim is much bigger here. It is to help and inspire students to appreciate the underlying themes of the experimental aspects or approach to engineering or science with whatever, in this case it was fluid flow lab, I have done it in many different labs, every lab it works very well. The main goal is to develop in students the ability to think with their hands. This has various ramifications, you can think about it, the ability to think with their hands.

In addition, this laboratory course aims to better the understanding of fluid flow principles, we could replace that with thermodynamic principles or bioprocess principles, to develop a physical feel for some fluid flow situations, to develop a familiarity with some commonly used fluid flow equipment, to inculcate a concern for safety to improve

the skill and communication of experimental results, to improve the quality of analysis and inquiry and to kindle the spirit of discovery in students. Seems like quite a bit, all this can be done in a lab course we have done it and what I am going to describe next is how we went about doing it.

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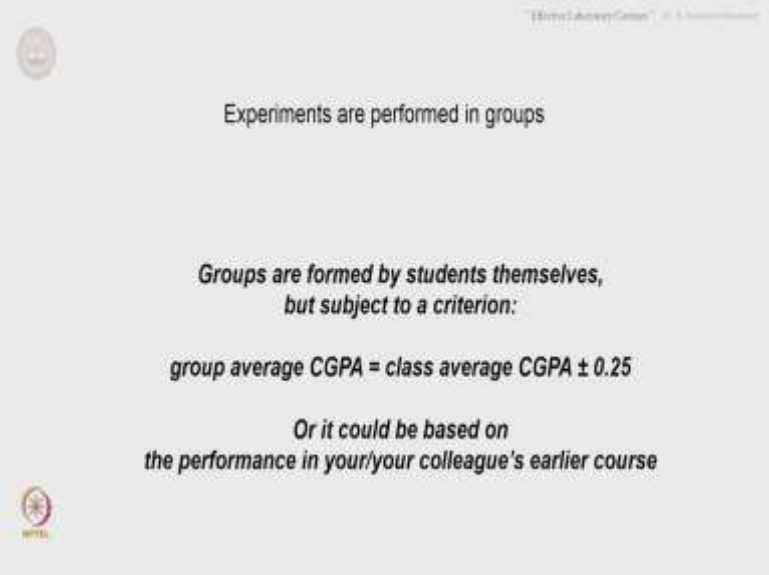

What we did was as usual this is nothing new, experiments are performed in groups, ideally 3 per group or 4 maybe. Beyond that it becomes a little too ineffective, 3 to 4 students per group. As was briefly mentioned in one of the previous lectures, these groups are formed by the students themselves. Now very early days I have been doing this from 1999 onwards, those days the CGPA was not considered a highly personal information. So, students used to give it out or you could always get that information from the office and you can ask students to form groups, such that the group average CGPA is the class average CGPA plus or minus 0.25, this ensures that each group average level is pretty much the same.

However a few years ago, here in IIT Madras people realized or students realized the personal nature of CGPA and they are no longer happy to tell it out to others and so on. In the earlier case, one needed to tell it out at least to their class rep so that the groups are formed right. In this case that I mean that change happened society societal change happened. And therefore, I had to figure out a different means of doing that. What I did was in this particular case I was teaching them a course earlier. Therefore, I used to take

those grades or those marks and use them as the basis to form groups. What I used to do was, if there are 3 students in a group or 4 students in a group let us talk about 3 students.

I used to create 3 sets depending on their standing in class in that particular course, in my previous course and give them these 3 sets, asked them to form groups themselves such that each group has one student from each set. If there are 4 students in the group, then I divided the class into 4 different sets, initially not very obvious as to what their performance had been. For example, the highest performing set of students would be called group D, the lowest performing students would be probably called group b and so on so forth.

As I said it is not very obvious, give them the sets through Moodle or something like that, ask the students to form their own groups, but ensure that there is one student from each set who is in the group. So, this is the condition. Even if you do not teach a course to them, probably a colleague can be requested to give the marks of their course. Any course is fine that gives you an idea. This is essentially some basis on which you could form groups. So, this is what is suggested if you could have better means of forming groups such that the average level of each group is pretty much the same, that is the main concept here.

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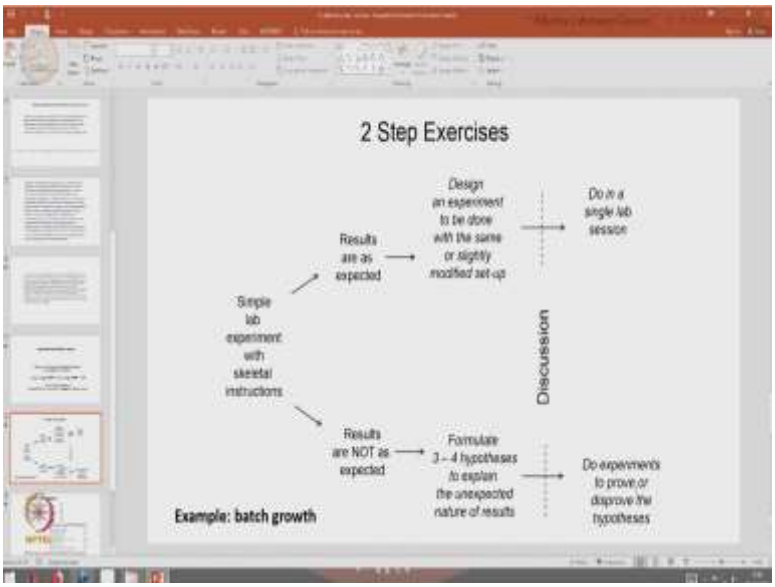

Then they do laboratory exercises in 2 steps. Each experiment is done in 2 stages. In the first stage, it is something like this. A very simple lab experiment with skeletal

instructions that are there in the guidance manual is given to students, the students need to you know read that, think about that and then come to class. Many of them do some of them do not, but that is fine and they therein need to perform the simple experiment that is deliberately designed to be simple in the first stage. The idea is that while doing this experiment because of the later needs that I am going to describe, the students will be more engaged in the process and they therefore, pick up a lot better rather than be overwhelmed by what they need to do in the first exercise.

So, in the first stage it is a simple lab experiment with skeletal instructions, the skeletal instructions are deliberate, no detail instructions are given. So, that they think about it. Then they do the experiment and there could be 2 ways in which the results could go. This could be a little unsettling for you in the beginning, but be with me, you will understand this. I am an experimentalist in my research, I know how experiments go I have done experiments myself hands on for my PHD and subsequently and so on so forth. I know how experiments go, this is how experiments go, irrespective of the field of engineering that one is in, chemical engineering electrical engineering, the details could be a little different, but this is how things go.

The results could be as expected or the results may not be as expected by theory, what they learnt in class, their notes and so on so forth. We normally completely ignore this. In this particular strategy I am saying that both are completely acceptable, because that is a truth right. I am going to describe a brief, the details of a brief experiment to you, will realize what it is. Probably if everything is highly determined and so on so forth, then this may not be very apparent, but maybe in a computer science thing there are equivalent aspects of this, maybe in an electrical engineering lab where you have well working or machines that work deterministically all the time and so on so forth, this may not be very apparent. But this is there, you cannot avoid it and these are people without experience at all, the students who are doing the lab for the first time. When a laboratory work which is a highly complex aspect, many different aspects determine whether you get expected results or not. These 2 are completely possible they happen all the time; results are as expected, results are not as expected.

In fact, if you start insisting that you should get this result and how dare you do not get these results, go and do it again, go and do it again and so on so forth, that sends a very wrong message to students. And if you think about it, we are showing the seeds of

plagiarism or cheating right here. Think about that a little bit, then you will understand the significance of what I am trying to tell you. So, here the results are could be as expected or are not as expected. Let us see them one by one.

If the results are as expected, good, then you design, they are expected to design an experiment to be done with the same or a slightly modified setup. This is what they need to do in the second session and the second step of this particular experiment or exercise. If the results are not as expected, they are supposed to formulate 3 or 4 hypotheses to explain the unexpected nature of the results that is all, why did they get unexpected results, it is well known from theory and experience by others, that these are the kind of results that you should get, but you did not get them, the students did not get them. Why did they why did the results turn out to be not as expected, they need to formulate hypotheses as to why this happened, testable hypothesis, testable hypotheses is what we need insist on or we insisted on.

Then at this point, they discuss with me. if I discussed with every single group after the first session as to what the results were whether it was as expected not as expected why and so on so forth. It is during this period when they sit in front of me, I insist that all the students of the group must be present for the discussion, I test in a discussion format, there are no marks for this discussion session, but I test in that discussion format which is very nice, the tone is in a discussion tone, it is not in a questioning tone, do you know this, you know how this comes about, very interesting did you really know that this happened, that kind of a tone is taken during this discussion.

And then this is when you realize that the students who are not highly skilled, the students who are on the left of the distribution of learning abilities, their confidence slowly improves. We do about 5 or 6 intense experiments, 2 stages. Therefore, totally about 10 to 12 experiments in a semester and as the semester progresses the confidence level of these people increases significantly and it is a beautiful demonstration of cooperative learning.

So, this is where the discussion happens, we discuss a lot. Their learning is improved, their understanding is improved as well as this aspect gets covered. So, in the second session after discussing with me, they do the new experiment. They have to design an experiment to be done, with the same or slightly modified setup. They get to be highly

creative in this aspect. Some of them have come up with very new aspects by this, a potentially publishable material has come out of this. They do it in a single lab session, the rudiments of a publishable materials has come out of this, then they do it in a single lab session for the second session.

If the results were not as expected, they had formulated their hypothesis, they had fine-tuned their hypothesis with that during the discussion session and they do experiments only to prove or disprove the hypothesis. There is nothing to do with the initial experiment, I will show this by an example to you. They do experiments to either only prove or disprove these hypotheses. If you look at this, the whole aspect of scientific learning has come into the picture here, hypothesis creation, hypothesis testing and so on so forth, that is what science is all about. It is a method right, this has come through very clearly here.

Let me explain this thing to you by taking batch growth which is a very standard experiment in biological engineering bio-processes and so on and let me explain that to you. Batch growth is nothing, but growth of cells under batch conditions. Batch conditions is, there is a medium which the cells utilize, may be bacterial cells utilize, and then they multiply by utilizing this medium, grow multiplied by utilize this medium. We are interested in following the variation of cell concentration in the batch, the medium is fixed the cells are put into that. Therefore, nothing is added, nothing is taken away. Therefore, it is called a batch.

It is nicely stirred and so on so forth. And you keep measuring the various things that you are trying to follow in this the parameters of importance that you are trying to follow during this experiment this is the experiment. And let me tell you how we did these various things.

Let me switch the applications here.

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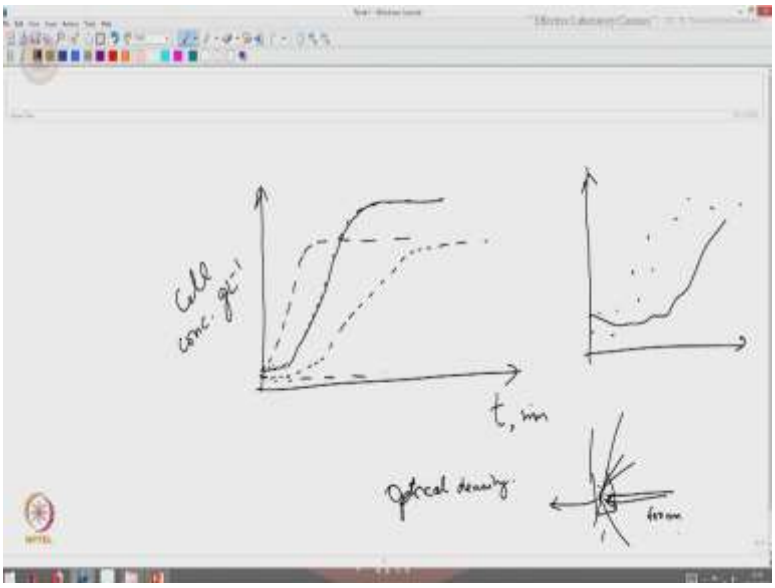

So, when they do this batch growth experiment first session with skeletal instructions and so on so forth, the first thing that they look at is how the cell concentration varies with time. They measure cell concentration at different points in time after the inoculum is added to the bioreactor and then they follow it with time, even if you do not understand some of these terms it does not really matter. And then they plot a typical graph of cell concentration. This is concentration typically in grams per liter versus time, maybe in minutes could be, whatever it is typically minutes. Hours is too long. We typically choose a bacterium that grows fast for the purposes of a 3 hour experiment and therefore, in minutes. Then they see variations, this is the expected variation of cell concentration with time.

Let us say that they have taken a large number of data points. I have shown the data points by points there and this period where there is not much of an increase in cell concentration is called the lag phase, this period is the exponential growth phase and this is called the stationary phase and so on. You do not have to worry about it. So, this is what they do.

In many situations, the cells could be at a stage where they do not see a lag phase at all. Therefore, their growth could be something like this, sometimes maybe for some somebody dropped in something there. Therefore, the cell started dying out and maybe they had never recovered or maybe they recovered after some time and grow slowly,

there are various different things that could happen depending on how the experiment is done, how carefully the experiment was done; and with students with no experience who do not even realize that these are important aspects, all these results are highly possible.

So, from here, when they measure cell concentration, they usually use something called optical density to measure cell concentration. This is quite a tricky concept because a spectrophotometer is used for the measurement and therefore, the standard thinking is that a spectrophotometer uses absorbance or measure absorbance and therefore, we are measuring absorbance of cell solutions to find cell concentration and so on so forth. Whereas, the principle is something like this, you take cells in a cuvette right, you have the incident radiation that is coming in here, these cells are of micron size. Therefore, they scatter light and whatever is not scattered is actually measured and from this, the amount of light scattered is calculated by the machine and that is absorbance, that is what it is given as and people students typically do not realize that it is cells scatter that they are measuring and not cell absorbance, although the machine typically measures absorbance.

And therefore, we deliberately use a wavelength of light that is not absorbed by the cells which is typically about standard thing is about 600 nanometers, which is used here and at this wavelength anything above 450 works 500 to 600 is perfectly fine, all this the students do not know, all this comes across during the discussion part, these are things that could come across during the discussion part apart from figuring out how their lab session itself went, whether it was as expected not as expected and so on.

So, how much is scattered and how much is measured and so on so forth. The wavelength used is 600 nanometers where the absorbance is minimum, the scattering is maximum and this is the principle of cell concentration measurement, this can be taught in a class. And then let me show you 2 situations; one is expected result the other one is not expected result. The expected result is something like this, some groups could get this that is perfectly fine, then they find out the specific growth rate compare it with the literature values to see whether it is fine for that particular organism and so on so forth. Then if it is all fine then they go ahead and do some other experiment. The standard other experiment is do the growth under different conditions maybe a different temperature, different pH and see the how these specific growth rate varies and things like that. That is what they do in the second session.

The more interesting part is if they do not get expected results and typically the data is not so clean, especially when they are inexperienced and they would have something like this. They need to make sense of it because the measurements require skill right, pipetting require skills and all these need to be picked up as a part of the lab and many students come up with things like this, they need to figure out whether it is worth using or and so on so forth or they could interpret this is not expected, why were there variations itself, could be one of the hypotheses that they could test, maybe my pipetting went wrong, how would you actually prove that the pipetting went wrong, it is another very interesting aspect they need to come up with and that is what they need to test in the second session.

Another aspect is maybe they found the data going something like this. So, why was there a decrease when you do not expect a decrease right? This could have happened. So, maybe one of the hypotheses is that the temperature was not set properly or maybe somebody added an inhibitor to cell growth right in the beginning without knowing, it just slipped in or whatever and these various hypotheses need to come about, some of these are testable, some of these are not. For example, I may have dropped something inside is not testable, that happened once, we do not really know unless it is very clear that that was what indeed happened.

So, to test that, what needs to be done is the same material needs to be dropped in and checked whether it inhibits growth and compare it with a standard control culture, where nothing is dropped in. The control culture shows actual growth and the affected culture shows slower growth, then it is proved that this could be a reason for the observed results. This is what I mean by the various hypotheses; one hypothesis is not good enough, they need to come up with 3 or 4 hypotheses and test them, and actually show which hypothesis is correct or not, sometimes all the hypothesis could be proved wrong and that is perfectly fine in the context of this lab.

So, to summarize we looked at the initial experiment with skeletal instructions, they do the experiment, the most important thing is the results could be as expected or maybe not as expected, both are equally acceptable. If the results are as expected, then they design a new experiment and do it in the second session after discussion with me. If the results were not as expected, they come up with hypotheses or a testable hypotheses for the reasons why they did not get expected results and just test the hypotheses and prove or

disprove the various hypotheses, this is the basis for this lab course. This would make it very interesting, very effective, they build various different skills is one way of doing that.

What I have not told you as yet is the evaluation criteria and let me show that evaluation criteria, which is the driver for ensuring success in this particular exercise. If you do all this and you do not pay attention to the evaluation, then students would not take it seriously. In fact, what I do is, I do not give any other exam in the lab. Each lab report is what counts towards a final grade and therefore, they need to work, they need to be completely involved in the lab experiments and so on so forth, the each report is graded as follows. If the results were as expected, the ability to follow procedures carries 10 percent the after each experiment 2 sessions they submit a report, one report per group and the reports are graded something like this.

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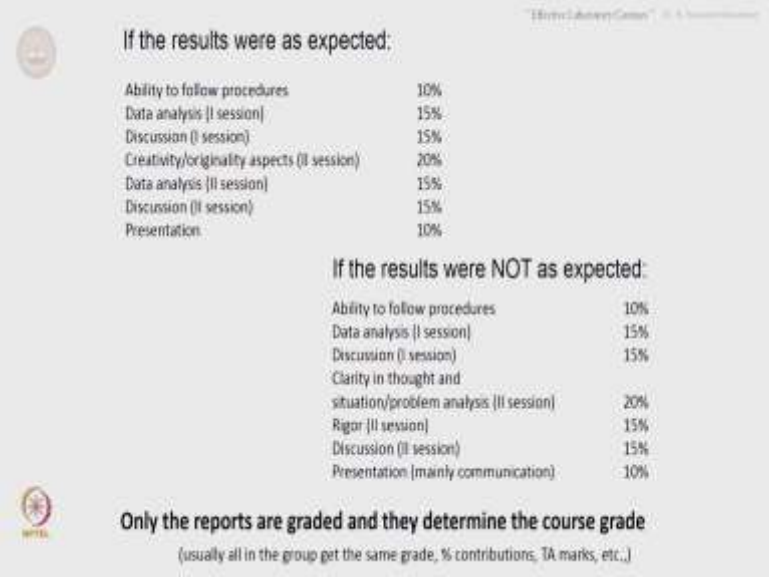

Ability to follow procedures 10 percent, data analysis for the first session 15 percent, discussion of results for the 15 percent which most students are not capable of initially, there are exceptions, but most students are not capable of initially this is a learnt skill and this they develop as a part of this that carries 15 percent. For the second session if the results were as expected creativity originality aspects carry 20 percent, data analysis for the second session 15 percent, discussion for the second session 15 percent, and presentation which is mainly communication and professional appearance of the report.

Communication carries 8 percent, then professional appearance with a report carries 2 percent, both are important, communication is more important. What I mean by communication is, if I read it once with concentration I must be able to understand, that is what I use as a criterion for good communication, that is very difficult to achieve for first time writers. But students get there, some of them are naturally good at it some of them learn as a part of this. Look at the different kind of skills that are being developed in students as a part of this laboratory course and a lab course allows you so much flexibility, so much possibilities and that is the beauty of it.

If the results were not as expected then the first session remains the same, ability to follow procedures 10 percent, data analysis first session 15 percent, discussion first session 15 percent. And then clarity in thought and situation of problem analysis, what led to their unexpected results, how would they go about proving that and so on so forth that carries 20 percent, the rigor if they do something and say that this is what resulted in a particular result or a particular observation, I should not be able to ask why did not you consider this other aspect, that other aspect also would have resulted into the same observation. So, that clarity, that tightness in their arguments is called rigor.

Then the discussion second session is 15 percent and presentation again 8 percent communication and 2 percent professional appearance of the report carries 10 percent. This this is how their reports are graded. I make sure that I grade them and give them back in 2 to 3 days. So, that they can use the input to improve their next report. Usually reports improve significantly in the first 2 or 3 exercises or the experiments. And then after the third session they improve, they kind of plateau out, they have reached a much higher level, if the learning itself has significantly improved including in report writing the communication and so on.

Only the reports are graded as I mentioned earlier and they determine the course grade and therefore, usually all in the group get the same grade, but I also make a provision to allow for differential contribution by members, some of them could be slackers. If the group decides to penalize them, then they give differential contribution percentages on the front sheet to me and I strictly follow those percentages with the signatures of all involved. They agree that this person has not contributed, the same person also agrees. If there is a difficulty/ conflict there, then they come and discuss with me and so on so forth. Therefore, that possibility exists and then sometimes the teaching assistants who

supervise the students during the lab and if the students are not well behaved in the lab, they do not follow instructions or they monkey around and so on so forth, then the ta has a means of communicating that in a way that is taken seriously - through marks.

So, that could also change the marks earned by the different group members, sometimes they may end up with a different grade, but usually most students in the group get the same grade.

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So, as I mentioned earlier the cooperative learning works wonderfully here. All students benefit as a part of this because of a cooperative mode of learning in groups and that group thing is impressed upon the, importance of group learning is impressed upon, because in the real world many activities happen in groups. Unless you do ivory tower research, theoretical research with just a pencil and paper. And most of the things you need to interact with people to get things done and this is impressed upon the students through this exercise. Also as mentioned, the confidence of students with low learning abilities improves significantly during the course and is very high towards the end, and that is a beautiful feeling, I think I will leave you with this for the lab courses.

Essentially, I have said that there is a way of making the labs highly effective and instead the traditional look at the labs or something to be done and finished with you could gain a lot more from the lab if appropriately designed. That is the whole message here. And that is all I have here, I should also tell you that you know this is for teaching in practice,

this comes under NPTEL online certification, therefore, there are assignments, there are exams and so on so forth. Please do them for the purposes, the formalities of the course, but the more important aspect is what you pick up and what you practice to improve the learning of your own classes.

Let me leave you with that thought today, when we come back later I think the next aspect is evaluation with which Dr. Richa Verma would take care off. Then will come back and talk about research in the learning process, how we can gain by the research in the learning process.

See you then.