**Virtual Reality Engineering**
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**Lecture – 39**
**Three Psychophysical Laws**

Welcome back. Today, we are going to talk about how to measure experience. Virtual reality is all about experience. The whole course is about how to improve the experience in virtual reality. In the earlier classes we saw that this course we are going to learn how to improve the immersion effects and the interaction effects. If you want to improve the experience, then the first thing we have to do is to measure the experience.

Only when we measure experience we can improve. Without measuring we cannot improve. All over your exams, not only virtual reality exams other courses also, there is an exam where you are measured your understanding. So, only when we give a marks or grade we come to know how much of your understanding of that particular concept is. Imagine without a measurement if we can improve, we cannot improve at all right.

So, same way here also, we want to improve the experience in virtual reality therefore, we want to measure. That is that today's topic.

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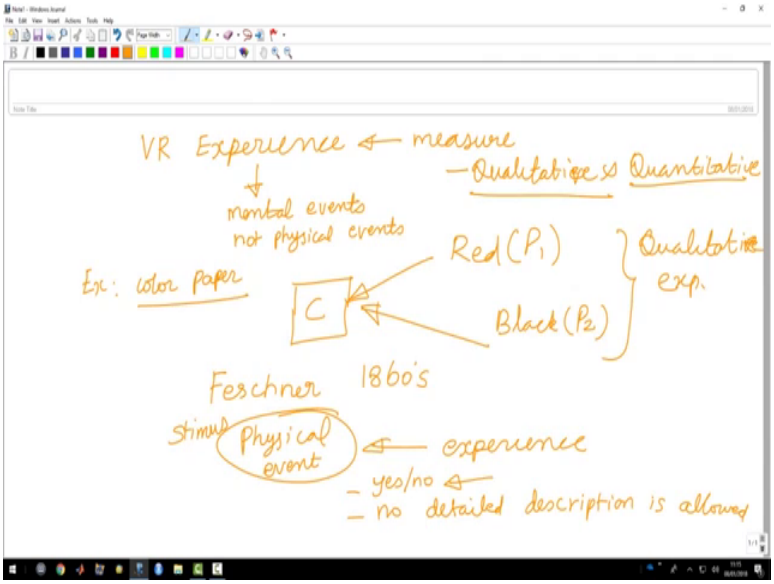

Let me write it oh let me write it down here. VR experience; we want to measure. All along we have been measuring experiences, suppose, we have gone to a movie and if your friends are asking how was your experience, you would say the experience is good bad or whatever your feeling is. That is also a measure of experience, but that is a qualitative measurement it is not the quantitative measurement. Qualitative measurement is good it is itself certain purposes, but it may not serve our purpose; our purpose of improving the virtual reality experience.

Qualitative measurements will not help and understanding in the virtual reality systems. So, the measurement we have qualitative and quantitative, what we are looking for is the quantitative measurement, quantitative measurement means we want to give some numbers to the experience. Measuring experience itself is a big challenge, that to quantitative we measuring the experience is even more bigger challenge. The reason is that the experience it is a mental event.

All in our engineering laboratories or science laboratories, we are measuring so many things, but those are physical events. They are not mental events. Physical events very easy to measure, there are instruments available, but it is very, very difficult to measure the mental events. Because the events are going inside the mind ok, not physically even, let me write it down physical event. So, how do we measure the mental events quantitatively is the whole challenge now.

We want to do this because we want to develop better virtual reality system that is one of the goals of the entire course. Without measuring quantitatively, the experience, we cannot improve the virtual reality systems. That is the reason we want to develop certain methodologies to measure the experience quantitatively; which will help us in improving the VR systems.

Let us take an example of looking at a colour paper, ok. Suppose if I have a color paper colored red and I am seeing it, and says this is a red paper, and my friends sees it and say it is a black paper. Suppose if I have a colour paper, let us say some colour, and I see the color paper on, and say it is a red, let me see, and my friend say it is a black paper, who is correct? Will not know; color is a mental concept; color is not a physical concept. color does not really exist at all ok, lights fall on the paper, and then reflection is what we see, and we are taught to name certain reflections as red black or green or whatever it is.

So, we all we have learnt to give certain names to particular light reflections. That is what the color is.

So, the color exists only in the minds of the subjects. We have our collaborator in the hardware psychology department. This professor makes us subject see a color photograph, and make some uh experience and the black and white photograph. Even though they are given a color photograph, but they what they experience is the black and white photograph, and the vice versa.

When they are given a black and white photograph collaborator makes a subject see a color photograph. The mental perception can be changed there are many ways of changing it for example, is as a hypnosis ok, that is what ma of collaborate reduce. So, the color is a mental concept it does not really exist ok. So, to find out whether I am correct, or my friend is correct, then we need to talk about, we need to ask the same question to many subjects, and if most of the majority of them say red, then I am correct otherwise my friend is correct. So, you can see that there is a problem in asking a psychological question. So, the qualitative uh experience.

So, the color is a qualitative experience, asking the subjects it is what the color is, it is a qualitative experience, experience, right. You can see the problem in naming it. This is a very simple question of asking what the color is slightly difficult concepts such as the contrast between the colours gets us into much more trouble. So, this problem of measuring the experience quant quantitatively is thought about by one of the scientists back in 1860s called Fechner.

Fechner in 1860's, he thought about this problem and came up with a very powerful suggestion. He looked into this problem, and then he observed that the experience proceeds with a physical event. In this case there is a stimulus, physical stimulus, in our example, there is the light falling onto the color paper, that is a physical stimulus, and then the reflections of the light reaches back to our eyes, then only we experience.

So, Fechner observed that if he can somehow relate this physical stimulus to the experience, then we may be able to quantitatively measure the experience that was his finding. So, instead of asking the subjects whether the color paper is a red or black, what he did it is a very very intelligent and design. He ask subjects only yes or no questions. The response is restricted to only yes or no. He designed questions in such a way that the

subjects can tell only yes or no answers. No detailed description is allowed, no detailed description, description is allowed in his method. So, by doing this he has propose a method to quantitatively measure the experience. How is that? For example, if you show many colors, and one of the color is let us say red then if you ask the subjects whether the red is present or not, the subjects are forced to say yes or no.

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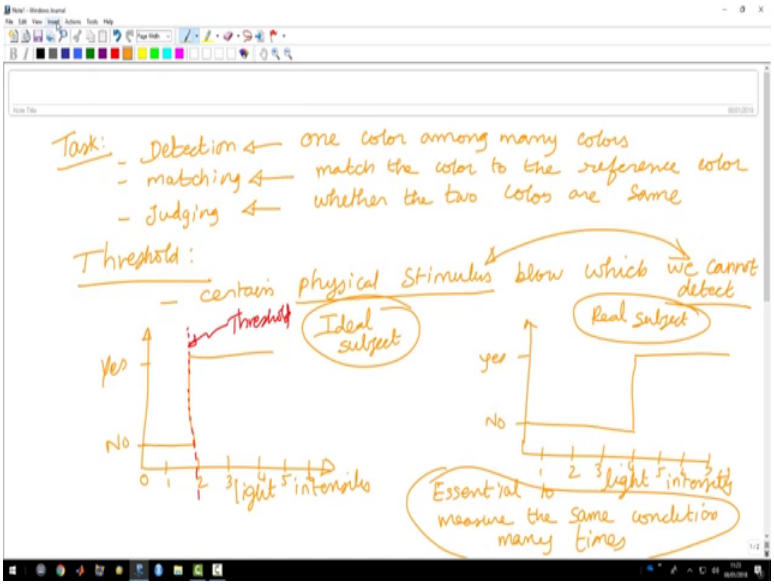


So, that is one task it is called the prediction task. One color among many colors or they can match their colours, it is called matching tasks, match the color to the reference colour, there will be a reference colour. And you need to match the reference color. And the third one could be judging, whether two colors are same, colors are same. So, in these tasks the subjects are allowed to say only yes or no question response they are not allowed to make a detailed description.

So, once yes or no questions; So, yes or no answers are there, then we can make a statistical influence, it becomes a statistical even and once we have the statistical even then we can derive so many mathematical quantities from the statistical event. That is what Fechner's brilliant idea is.

So, it is almost like the game which we play in our childhood, that at least I remember I have play when I am child we ask that our friend to think of a person or a name or oh object, and we will ask the question and the friend is allowed to say only yes or no, the number of questions we ask to find out what the friend is thinking, measures the our

ability to ability to you know a guess quickly or how we affectionately we could guess what he thinks about. That is exactly what the Fechner's method is about. The lesser number of questions I ask in order to find out what my friend thinks, the sharper or I am or whatever it right.

So, that becomes a quantitative a measure of my ability or my friend's ability. So, we are thinking of similar quantitative method to measure the experience ok, I making it very simple; So, that now you can relate to what you already have experienced that in your childhood.

Once you have this yes or no response, from this, Fechner derives a quantitative concept called threshold. Threshold is an important concept in the whole of virtual reality ok. So, he defines the threshold is certain physical stimulus, certain physical stimulus below which we cannot experience we cannot below which we cannot detect cannot detect. Below which we cannot experience at all, right. It is a physical stimulus, and detection is an experience, the simplified experience where will have to say only yes or no. This way this is this two things are related, right.

For example, if you say we can put it in a graph, let us say in x axis we have this light intensity in which, what is in which we are trying to find out what is the minimum light intensity required for us to detect the light. Let us see in the y axis we have no and yes response. Let us name the x axis let us say one 2 3 4 5. Let us say in one example the subject says no until the light intensity is raises from 0 to 2, and then a 2 let us say he detects the light.

This case that the threshold is, 2 let us say this is a arbitrary unit. He is a ideal candidate if he is an ideal candidate, every time we repeat this experiment at a 2 units of light intensity, he will say yes, after 2 unit he will say yes, ok. So, let us assume that he is a ideal candidate ideal subject. The ideal subject will always respond yes to all the light intensities above 2, and below 2 he will always respond no.

But the real subject will not behave the same way he there will be a variation every time you repeat an experiment. Let us say next time when you repeat the experiment no, yes y axis 1 2 3 4 5 6 7. Let us say he responds only at 4 unit, the real subject. So, his response is changing because there is a noise in the sensory system. Sometimes, he response yes after 2s sometimes he responds and yes there is only at a 4. There is a variation. Subject

to subject within the subject itself this variation is there, that is natural. That is a random process, right.

So, it is essential to measure the same condition many times, essential to measure the same condition many times and if we after measuring many times if it plot a curve.

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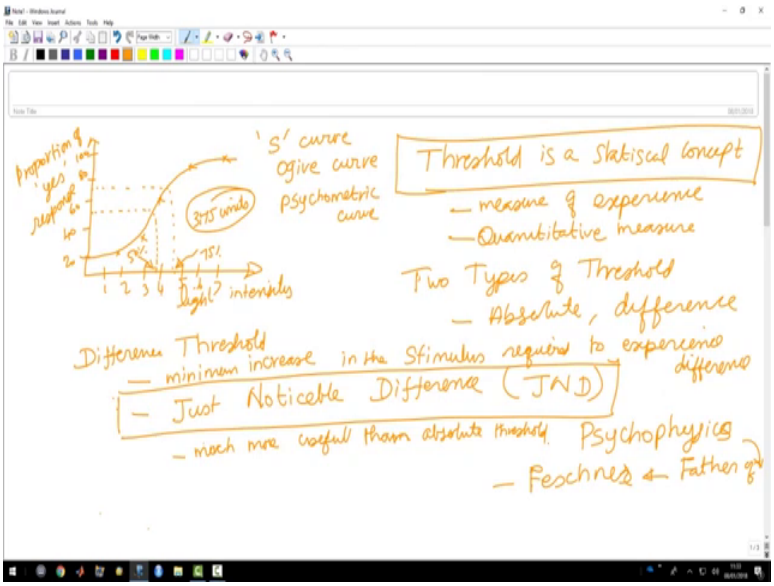


Let us say again x axis going to be light intensity, and y axis is going to be proportion of yes portion of yes response. Let me say 20 percent here, 40 percent, 60 percent, 80 percent, 100 percent. In the y axis I am plotting proportions of yes response at each of the light intensities. When the light intensity was 2 unit, let us say there are around 20 percent of the responses were there, when I increase light intensity 4, then there were 60 percent, and then 6 there were more and then 7 there were 100 percents, ok. Let me put it over here, yes, some other 3 where it I have some other number.

So, let us an hypothetical situation let us say this is what the data looks like. Now we can connect this lines and to give you a curve something like this, so that the challenge is to find out what is the threshold from this curve. Because every time the response is changing, the concept that the threshold is changing, how do we find out what is real threshold. We can assume that whatever the from this curve this looks like a s curve. So, it is called the s curve s shaped curve or it is called the ogive curve. Ogive curve or it is also called the psychometric curve psychometric curve all are the same.

So, from this curve of a particular task of a particular subject from this curve we can measure the threshold. Let us say what is it threshold at 50 percent of the times the subject say yes. in this case, let us say, 3.75 units, and other times this may be no more or less let us. So, some subjects considered that at instead of 50 we should considered as 75.

This is 75 percent threshold at a 75 75 percent this is a 50 percent threshold. So, we are going to talk about this problem again in their, your assignments you will be given example problems, where the concept of threshold will be made very clear. So, I am going to ask you to wait until you get a better experience. So, if this at this point of time, the only thing I want to highlight is that threshold is a statistical concept.

So, we saw that threshold is a measure of mental events quantitative measure of the mental events, and it is a statistical concept, is a measure of mental events and let us say experience quantitative measure of experience t h of measure of experience, and it is a statistical concept. It is not deterministic concept that is all I want you to remember at this point of time.

Now, threshold there are two types of thresholds. One is the absolute threshold r and difference threshold, difference threshold absolute threshold is the one and below which you cannot experience. Difference threshold is one if you already experience certain light intensity. How much increase in the light intensity is required in order to feel the difference? So, different intensity different threshold difference threshold, let us define it as minimum difference in the stimulus in the stimulus required to experience, minimum difference minimum let me say increase in the stimulus required to experience the difference, that is the difference threshold.

The difference threshold it is called the just noticeable difference, noticeable difference or in short it is JND. JND is one of the most important concepts in the whole of virtual reality you may have to learn. This subject of measuring the experience quantitatively is also called the psychophysics. So, Fechner is a father of the psychophysics, Fechner is the Fechner is the father of the psychophysics.

He has introduced this concept 200 years ago, and in the psychophysics the one single most important concept is the just noticeable difference. Although the absolute threshold is going to be useful, JND is as much more useful than the just noticeable difference JND is much more useful than threshold.

So, there will be there are lot of psychophysical data books available for different stimulus input stimulus physical stimulus. People have done experiments, and then they have measured these just noticeable differences and then they have put it up put it in the data books. You may have to refer these data books to find out these just notable differences in order to be useful in your design. So, let me write it down again, much more useful than absolute threshold. So, mostly we will be using (Refer Time: 27:40) JND ok.

Now, how do we use this is the concept of the threshold for measuring the experience? Let us imagine that let us come up with us scale for experience.

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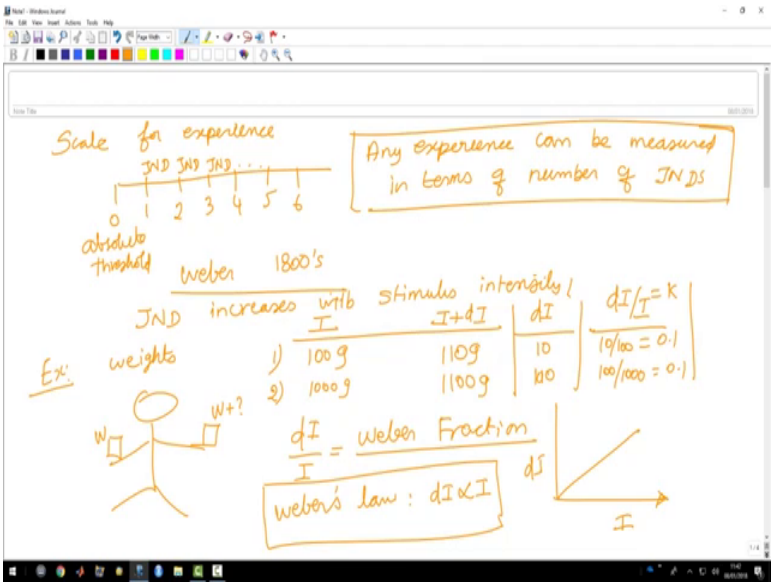


I have a ruler scale with me this scale measures of the length, there are marks written over here 1 2 3 it is all either in inches or centimetres it is written. These are the measurements for the lengths as we have been you know using it. Similar, scale can we come up with for measuring the experience? So, the scale starts with 0 over here, similarly our scale can start with 0, and that 0 is nothing but the absolute threshold, because below which we cannot experience anything let us see absolute threshold.

From this absolute threshold what is the minimum increasing the light intensity or physical stimulus intensity needed in order to perceive the next difference that is the first JND. Then from the first JND again we need certain amount to be increased in order to experience the next difference that is second JND. Similarly, third 4th fifth 6th, these are

all first JND second JND third JND forth JND and so on. This is a scale for experience. So, any experience can be measured in terms of number of JND's, let me highlight it.

So, even though we call Fechner as the father of the psychophysics; Before Fechner there was another scientist whose experimental data where useful for Fechner's to design the psychophysical field itself. His name is Weber in 18 let us say 18 100s, he found that JND with physical intensity, the stimulus intensity. So, he actually did one and very famous experiment, he used to weights instead of light intensity, weights see he took a subject he put weight in both the hands of the subjects, let us say w in the side.

So, he wanted to measure what was the extra weight needed for the subjects to feel the difference. So, he is let us in his case he started with let us say a 100 gram. And the subjects required had 100 and 20 grams in order to fill the difference. The next case, we put thousand grams because this is 100 100 and 10 gram. The next case when the subject are given thousand grams, then they needed thousand 100 grams in order to fill the difference.

So, suppose if he gives some symbol like I to the initial weight, and then the final weight with which they can feel the difference is I plus some change in the I, then Weber observed that this JND this is a JND d I is nothing but the JND over here, this is the 10 gram this 100 gram Weber observed that JND increases with a stimulus intensity. But that d I by I he observed that that is actually constant. In this case 10 by 100 is equal to point one, this case oh this is 100, only 100 by thousand is equal to point one.

Weber's observation is that dI by I is equal to a constant. In fact, this fraction d I by I is called the Weber fraction.

Most of the psychophysical data books will mention this Weber's fraction. So, if you, if we draw x axis with the I, and y axis with the dI, we will see that it is increasing linearly. This law is called the Weber's law. Weber's law is equal to d I is proportional to I, and the proportional constant is the Weber's fraction.

Weber's law is one of the most fundamental laws, one of the first laws in the psychophysics. Fechner use this law for building the whole field of psychophysics. Although Weber did not come up with a concept of the threshold, but all the data were there for fitness to invented and cover with the concept of threshold and just noticeable

differences. Apart from this Weber's law, Fechner has come up with another very important observation.

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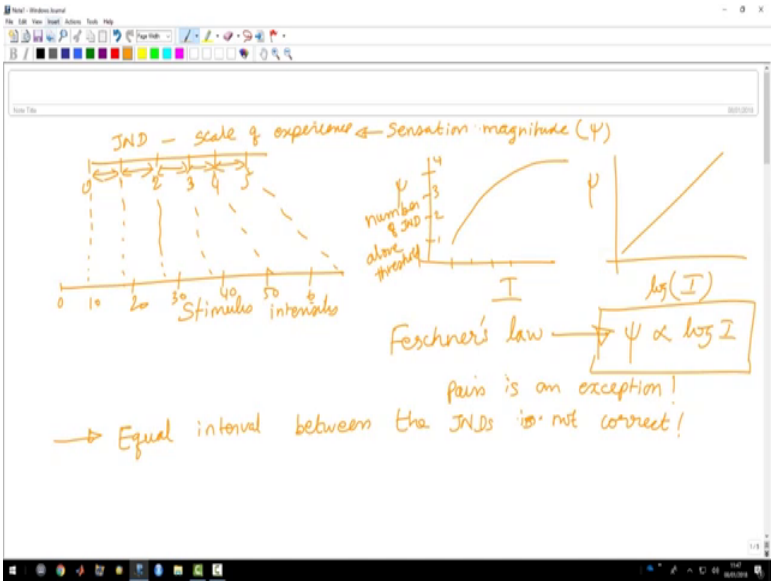


He found that in the scale of experience, when we have this JND number of JND's 1 2 3 4 5 JND's, the scale of experience. Let us also call that as a sensation magnitude. These are all some of the technologies, you may have to get used to it. So, that when you come across in the literature in the reference books, you know what we are talking about, right. He observed that the physical stimulus, the stimulus is not uniform.

For example, let us say this is a light intensity in this case, this is going to be sub 10 20 30 40 50 60, then the JND's or result of non-uniform increasing the physical stimulus, stimulus intensity in fact. So, this can be put it into another graph stimulus intensity. Let us say I, and let us say this is nothing but the psi number of JND's. Basically, number of JND's over threshold, number of JND, about threshold.

Let us say one 2 3 4, and what he found out that it is not linear. It is saturating over here, as the physical as the JND's increases more and more increasing the stimulus intensity is needed it what Fechner's as observation is. In fact, he says that there is a logarithmic relation between this I and the psi. So, if you take off log of I and then psi over here, then there is a linear relation.

So, this observation can be put it on a equation is proportional to log of I. This relation is named after Fechner, and it is called the Fechner's law. Fechner law is that that the sensation magnitude the scale of experiences JND's is directly proportional to the log of I. It is not just proportion. So, again Fechner's law holds good for various stimulus, but there are some few exceptions; Exceptions for example, pain is an exception, exception to the Fechner's equation. And also, Fechner's assumed equal interval between the JND's; which is not correct, equal interval, interval between the JND's is not correct.

So, if you look at a this interval, he assumed this to be equal, that is what Weber also has found out, and he assumed Weber is correct. Therefore, he derived this relation of logarithmic relation between the intensity to the sensation magnitude is not necessarily correct is what a later (Refer Time: 39:35) in fact.

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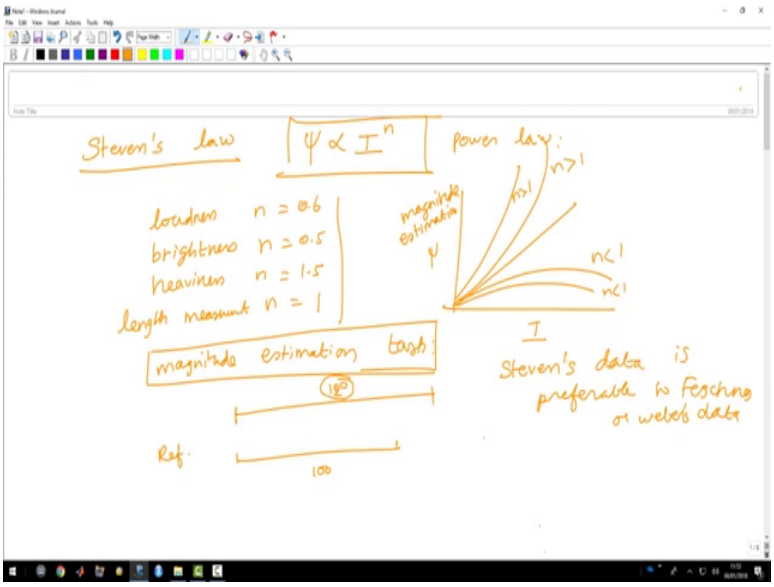


There is another researcher called Steven, we are going to talk about. Here we find Fechner's law and came up with his own law called the Stevenson law. He says that, the sensation magnitude is directly proportional to the not logarithmic psi, but to the power of I. There is a power relation exists between the sensation magnitude, and the intensity is what the Stevenson had come upon.

Stevenson is about very recent time maybe about 50 years ago, he was a professor in the hardware, and he has generalized Fechner's like law. In fact, there are no exceptions found for Stevenson laws, all the physical stimuli follows this power law of

psychophysics. For each of the stimulus, people have measured there is a n, and then they have just listed out of it for example, la loudness n is considers 0.6 brightness n is equal to 0.5 and heaviness n is equal to 1.5 length measurement n is equal to 1. While deriving this number, Stevenson has slightly modified Fechner's equation, Fechner's experiment itself.

He did not find out the JND instead, he considered magnitude estimation task. It is slightly different, estimation task. See in the magnitude estimation task, people are given one object, and they are given a reference object this is a reference. They are given a number, with respect to the reference, they are asked to a quantitative measure of another object. Let us say the subject gives 100 and 20, or somebody else will give 100 and 40, ok. So, this way there are some biases inherent in the Fechner's experiment or avoided ok. So, in fact, in a Stevenson law, it the y axis is mentioned as magnitude estimation.

This also is the same as psi, there is not just JND, then here it is considered as I, then there is a of course, linear relation for certain things; for example, the length measurement what we talked about it as a linear measurement. For some other things it increases, for some other thing it is actually decreases.

So, here n is greater than 1, n is greater than 1, here n is less than 1, n is less than 1. If n is less than 1, then more intensity is required for in increasing the experience. For a condition where n is more than 1, less and less intensity is required to experience, and more and more the physical stimuli. So, most of the conditions Stevenson data is preferable, wherever is available, Stevens data is preferable to Fechner or Weber's data, Weber's data. That is because the way this magnitude estimation task is done. This is slightly better than the JND does task.

So, we will stop here. We initially started with looking at how to measure the experience quantitatively. We came up with this concept of threshold, and then there derived concept of JND; which is a much better concept than threshold itself. We looked at the Weber's law, we looked at these Fechner's law, we look at the Stevenson law, and then we looked at what are the problems with Weber's law and Fechner's law, and how Stevens refine these 2 laws to a much more general psychological law.

If you look at the literature the data for all the 3 laws may be available. So, you should know which data to use in which situation. In fact, all the 3 laws are only are called

classical psychophysics. The concept of threshold itself does not exist this, what the reason psychophysics, psychophysiology says that belongs to the advance the psychophysics course which we offer as a separate semester course here in IIT madras, which you do not have to worry about.

If you are aware of these basic fundamental 3 laws of psychophysics classical psychophysics that is good enough, that will help you to design better virtual reality systems.