Teaching and Learning in Engineering (TALE)

Prof. N.J. Rao
Department of Electronics Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 13
Vincenti Categories of Engineering Knowledge

Greetings and welcome to the Module 1 Unit 13 on the Categories of Engineering Knowledge.

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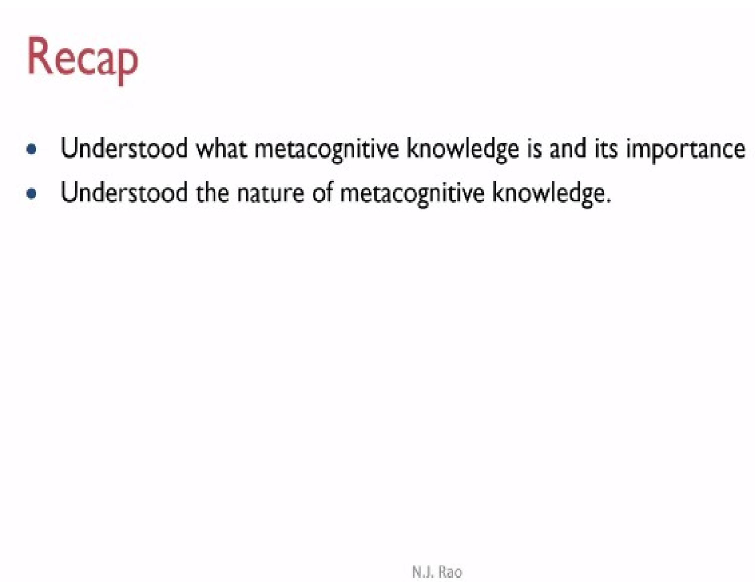

In the earlier unit we understood what metacognitive knowledge is and its importance and also we understood the importance of giving instruction in metacognitive skills to weaker students and also understood the nature of the metacognitive knowledge itself.

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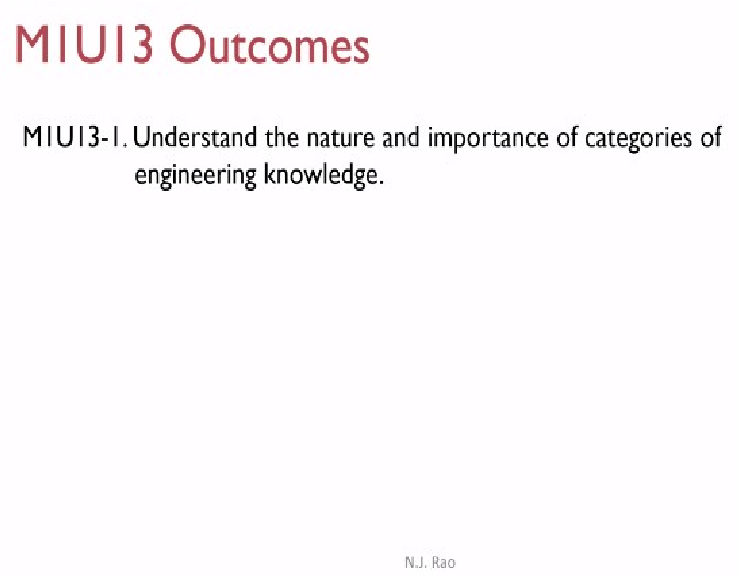

Now, coming to this unit, the outcome is understand the nature and importance of categories of engineering knowledge. So here you have this. Is there anything called engineering knowledge separate from what we have already looked at? We looked at four general categories of knowledge namely Factual, Conceptual, Procedural, and Metacognitive. Should we really consider any other category of knowledge? Some people differ on that.

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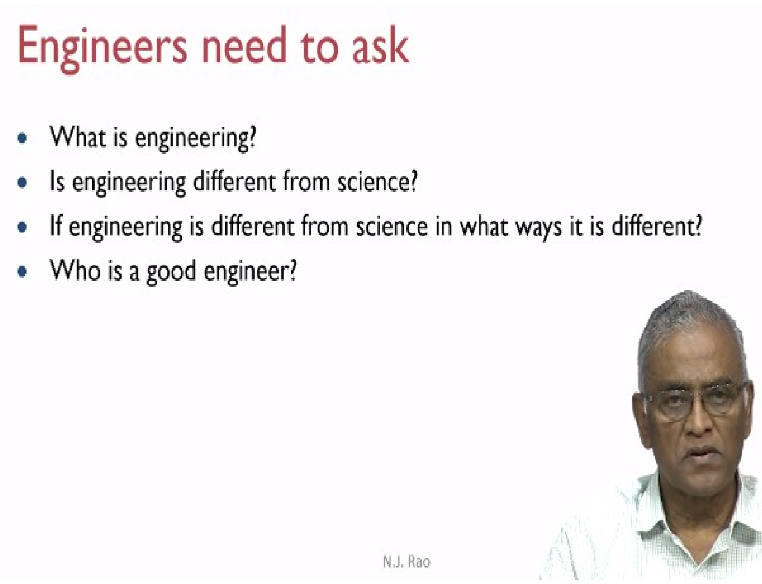

So if there are some specific categories of knowledge that engineering/ engineers and engineering students need to look at so we have to get back to basics saying that we need to ask what is engineering? Is engineering different from science? If engineering is different from science in what way it is different? And who is a good engineer? We have talked about already who is a good engineering in the very early modules.

And the nature of good engineer is defined officially by the National Board of Accreditation. We will not dispute that even if we have different opinion. Officially it is defined through what they call as Program Outcomes.

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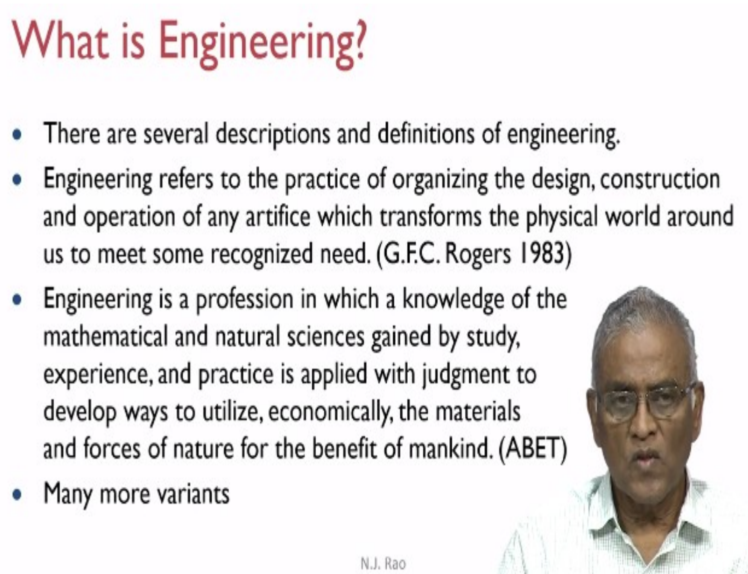

Now, there are several descriptions and definitions of engineering over the last maybe 150 years and here we look at two or three or there are several variants of this but in the end all of them they say approximately the same thing. Engineering refers to the practice of organizing the design, construction, and operation of any artifice which transforms the physical world around us to meet some recognized need, okay?

This is one way of definition that there is a need that is identified in the physical world around us and engineering is organizing the design and construction and operation of any artifice that meets the requirement of somebody. That is another way of saying the same thing. Engineering is a profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize economically the materials and forces of nature for the benefit of mankind. This is as given by ABET.

Earlier was given by Rogers. Now interestingly even an accrediting organization put something like the process before the output. The first you define the process that is knowledge gained through various means is applied with judgment but what is the goal actually? Develop ways to utilize economically the materials and forces of nature for the benefit of mankind. That is the goal. That ought to have come in the beginning rather than at the end.

But that is the way unfortunately many times the outcomes are written. And there are many variants of this. They are not at great variance with each other. They emphasize depending on the situation different aspects of the, what you call utilization or designing the artifice. So that is what engineering is.

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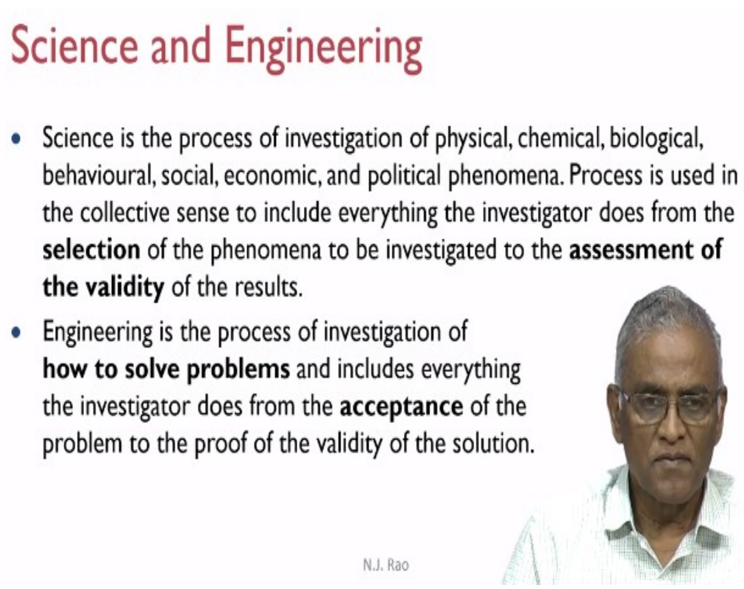

Now, here is an interesting definitions of Science and Engineering. The way they are written they are brought very close to each other. Here science is a process of investigation of physical, chemical, biological, behavioral, social, economic and political phenomena. Process of investigating these phenomena. Process is used in the collective sense to include everything the investigator does from this selection of the phenomena to be investigated to the assessment of the validity of the results.

So here what happens in science, you are trying to understand phenomena in the nature. You are actually discovering the relationship between various facets of a particular phenomena. And you have to say whatever conclusion that you have come to its validity should be established. Whereas engineering is a process of investigation of how to solve problems and includes everything the investigator does from the acceptance of the problem to the proof of the validity of the solution, okay?

So the highlighted points are the points for comparison between science and engineering. Here is someone who has written these two trying to bring them as close to each other as possible.

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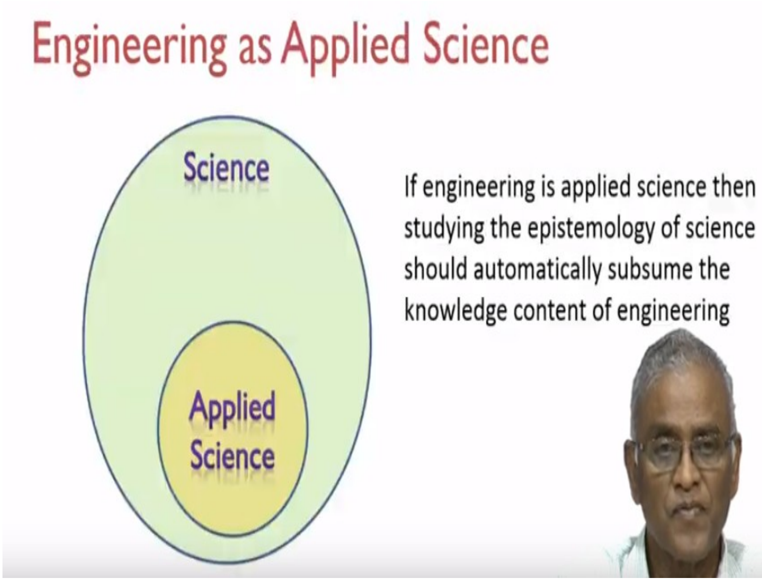

Now, coming to this, many times you see more than scientists, engineering professors themselves trying to call engineering as applied science which in my opinion is very unfortunate and also incidentally calling engineering as applied science has political implications which we will not go through but if you call engineering is applied science that means it is science with some adjective added to that. So it becomes a subset of science.

So what happens is if this is the view of engineering, if engineering is applied science then studying the epistemology of science should automatically subsume the knowledge content of engineering. That means we have already talked about four categories of knowledge of science and then if you are dealing with that then you have also dealt with that, what is relevant to engineering as well. But that is not the stand we would like to take.

And actually our experience shows when you probe engineering teachers or those who are teaching engineering subjects, if you probe them further while many of them start with the concept of applied science with a little probing they will come and say yes this is what the relationship between engineering and science.

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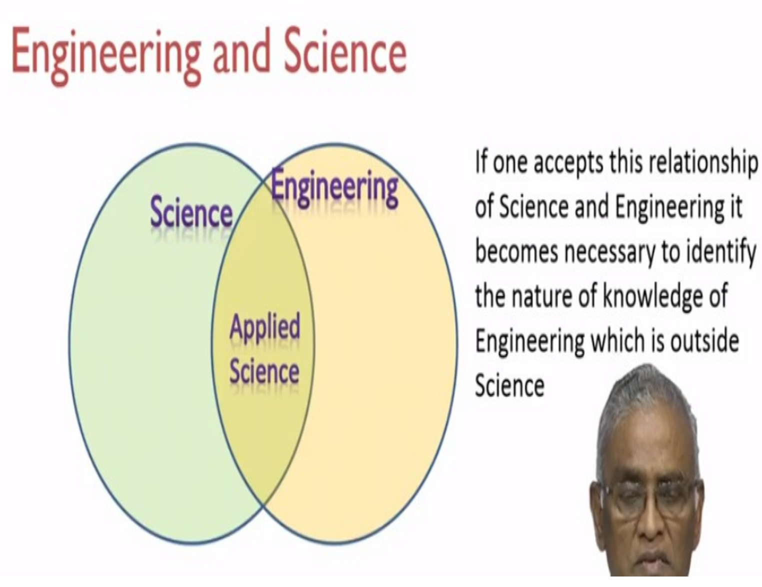

Now, engineering is not a subset of science nor a superset of science. It is something different. Different in the sense its goals and its methods are different from the goals and methods of science. Now if you look at this there is obviously strong interaction between the two. If you want you can make that intersection between science and engineering as large as you want. But still something in engineering that is outside science or outside applied science does exist.

And what is the nature of that thing that exists outside is science and that is important to engineering. Unfortunately over a long period of time, engineering way it is taught has predominantly become applied science. That means engineering subjects are somehow purged out of engineering programs and they have become dominantly engineering science programs. It is not that engineering sciences are unimportant.

But you cannot throw away engineering from engineering. And that is because the area that is outside science and inside engineering has not been attended to. So if one accepts this relationship of science and engineering it becomes necessary to identify the nature of knowledge of engineering which is outside science. That is what we are going to do that.

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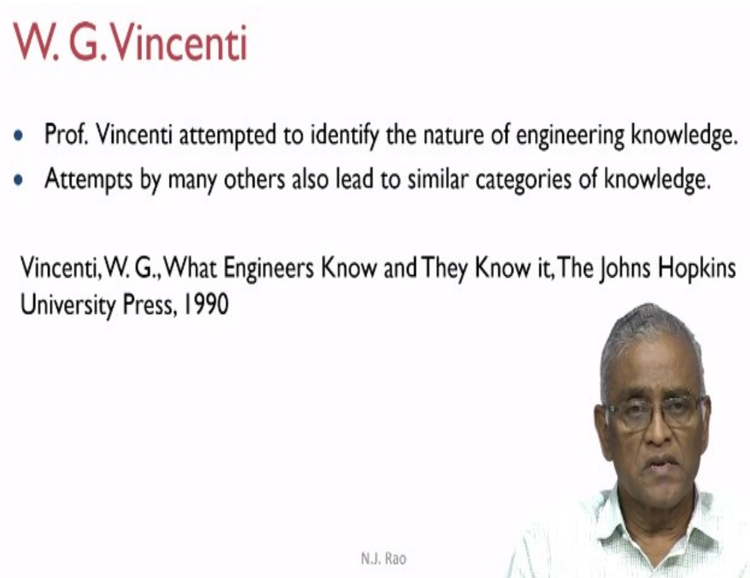

Here we will go with what professor Vincenti of Stanford University has done. Professor Vincenti attempted to identify the nature of engineering knowledge in his famous book written back in 1990. What engineers know and how they know it actually, sorry. Many others also have attempted through categorize engineering knowledge but all of them are somewhat similar, not very different and we find that Professor Vincenti's classification is comprehensive, is kind of subsumes other types of categorization.

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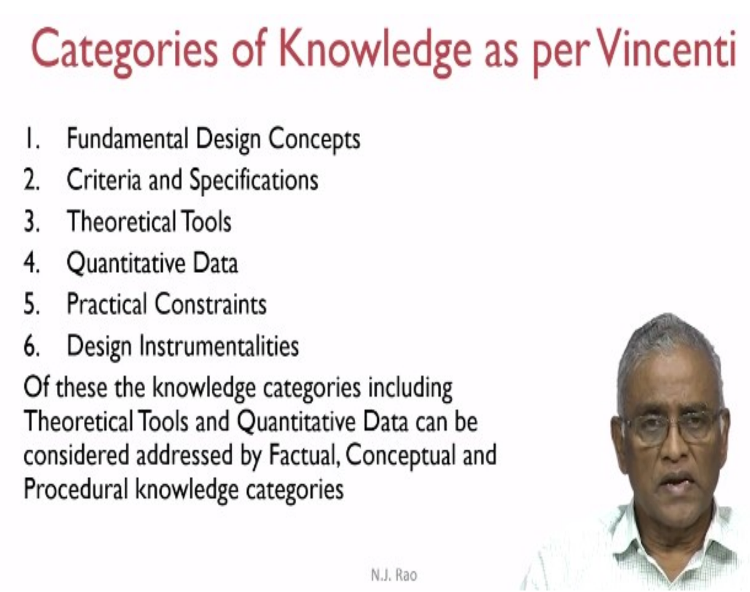

Now what he has presented, categories of knowledge as per Vincenti, there are six categories that he talked about. That means looking at engineering per se - these are Fundamental Design Concepts; Criteria and Specifications; Theoretical Tools; Quantitative Data; Practical Constraints and Design Instrumentalities. These are six categories.

Of these knowledge categories, the theoretical tools and quantitative data can be considered addressed by our previous categorization namely Factual, Conceptual, and Procedural knowledge. That means two of the six are already addressed by general categories of knowledge that we have already dealt with.

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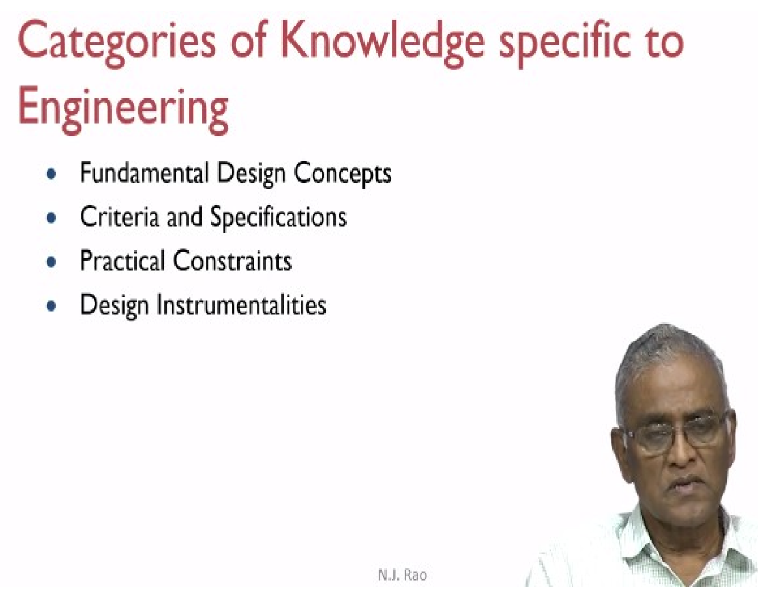

So what remains is this. Categories of knowledge - specific to engineering which are outside the general categories, they are Fundamental Design Concepts, Criteria and Specifications, Practical Constrains and Design Instrumentalities. Now what one should be cautious about, the nature of knowledge in these four categories will not be exactly similar to let us say conceptual knowledge or procedural knowledge.

They may be less abstract and they will not be at the same level as we would consider. Let us look at each one of them.

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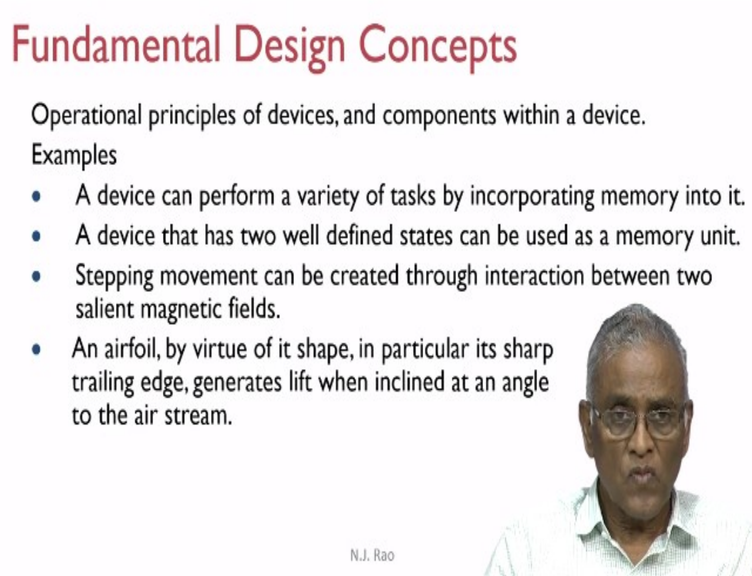

Fundamental Design Concepts - operational principles of devices and components within a device. That is what fundamental design concepts. What happens is, knowing the underlying science or physical phenomena or chemical phenomena or biological phenomena it does not automatically lead to design concepts. Design concepts are generated completely outside these four categories and a design concept can be explained within/ with the underlying science.

But not it cannot automatically come out as a consequence of knowing the science. For example, let us look at some examples in engineering that we are familiar with. But what happens in practically all the engineering subjects, we grow with these design concepts without almost paying any attention to them. But somebody has come out with design concept and it becomes part of our day to day work practically in engineering.

For example, a device can perform a variety of tasks by incorporating memory into it. This is in electronics once you are able to put memory into something into a device it practically it has changed the entire field of electronics. That is where the microprocessor have come in late '70s and early '80s and the world is not the same anymore. Today, you have a microprocessor which keeps using this design principle, and we have designed such powerful microprocessors and the devices that we use today whether it is laptops or smartphones are the result of this fundamental design principle.

And still earlier principle a device that has two well-defined states can be used as a memory unit. For example, the entire memories that we use as a part of our pen drives or any other memory is the result of this particular design principle if we have two well defined states of any device and you have some control of keep switching the state of the device it can become a memory.

Till today, even now people are still finding out at atomic level how can we identify two independent states and control or rather stable states and where we can control this switching over from one state to the other by making that physical device or atomic device smaller and smaller we are able to kind of bring more and more memory into a smaller and smaller place.

Another fundamental design concept, stepping movement can be created through interaction between two salient magnetic fields for example all the step motors that we use in various industrial automation are the result of this design concept namely that interaction between two salient magnetic fields and the most famous one an airfoil by virtue of its shape, in particular its sharp trailing edge generates a lift when inclined at an angle to the air stream.

That is all our flying objects are the result of this, but until this principle somebody has identified we really did not have the proper airplane. But now it is taken for granted this kind of principle. If one can produce, if an engineer can produce a fundamental design concept it just changes that line of world completely. But as a student of engineering one should be aware of the role of these design concepts in the subject that you are dealing with.

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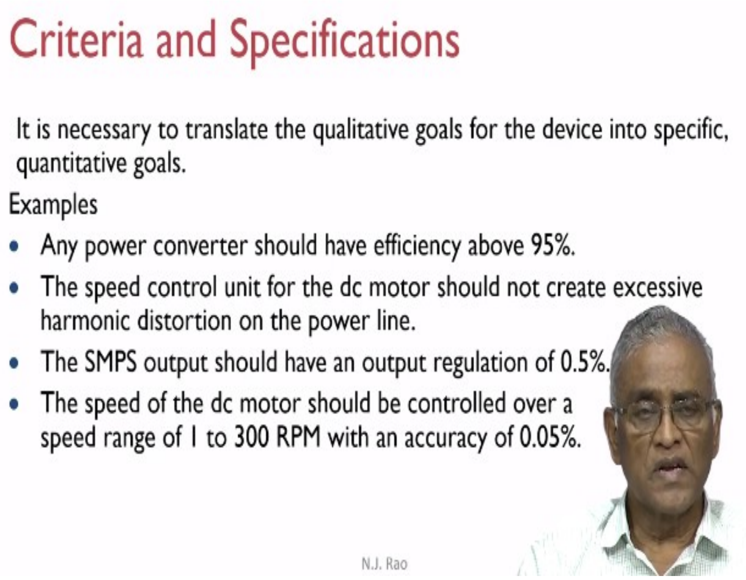

Coming to another important one in my opinion most central to engineering is criteria and specifications. It is necessary to translate the qualitative goals for the device into specific quantitative goals. It looks very simple statement. What happens if you look at all the text books that are followed in engineering we hardly the books hardly mention anything about criteria and specification.

There is no engineering activity out in the field where you do not start with criteria and specifications. If you are working in a company, whether you are a part of a software team, software product team or a hardware product team, if you are considering any project in any company, the first thing is to decide what exactly are you trying to produce. When you talk about that, that is expressed what is to be done is written as some set of specifications.

And if you err on the specifications, if you do not define your specifications adequately for the product, either it becomes too expensive if you over specify or if you under specify it will not be acceptable to the market. It can become a very crucial decision. The importance of criteria and specifications somehow is not taught at all in the present day engineering programs. And this should be integral part of any engineering course that you have.

A student should grow all the time with the, with understanding what specifications are and when you chose a specification what does it mean? What does it mean either economically or the time taken or the technology is used? these are all decided by the criteria and specifications. Let us look at some simple examples. Any power converter that is when it converts from AC to DC or DC to AC should have efficiency above 95%. If you design one power converter that has only 70% efficiency it is of absolutely no use to anybody. Nobody will ever touch that. The minimum efficiency is 95%.

So right from the beginning, this specification should be part of your entire design exercise, not just functionally what a power converter is. All decisions regarding the choice of devices, circuits everything should be first thing to be met is the efficiency has to above 95%. But a product may have other specifications. For example, it may have a, what do you call specification on the footprint or how much it should weigh, what is the power it should be able to convert.

So there may be several other specifications but one central one, if it does not have 95% it is of no use to us. The speed control unit of the DC motor should not create excessive harmonic distortion on the power line. What is that excessive is normally defined by some agency, regulatory agency. So it should not produce harmonic distortion on the power line. It may meet your speed control requirement.

But if it does not meet the harmonic distortion it will not be certified. SMPS output should have an output regulation of 0.5%. If it has anything more than that it will not be acceptable in the market. The speed of the DC motor should be controlled over a speed range of 1 to 300 RPM with an accuracy of 0.05%. Now for example instead of 0.05% if I say 1% the cost of that unit will be maybe 100 times less than a unit that provides the accuracy of 0.05%.

So one should be very careful, the engineer should be very careful in over specifying the accuracy. If the application demands that yes by all means you have to meet that. But otherwise, one should not over specify. So we have given you only four examples but that kind of situation arise in every branch of engineering at all levels. So the student should be particularly be made sensitive to discuss the criteria and specifications with regard to his branch of engineering.

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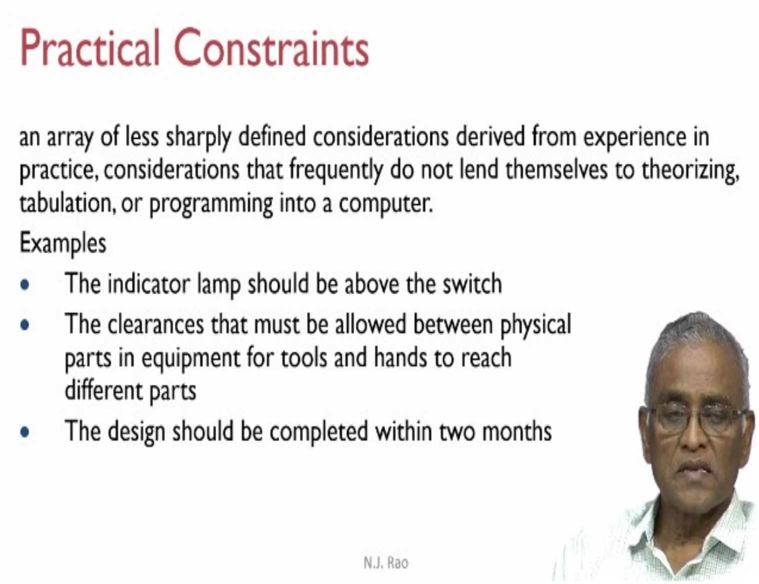

Now, the third category of knowledge is Practical Constraints. They refer to an array of less sharply defined considerations derived from experience and practice. Considerations that frequently do not lend themselves to theorizing tabulation or programming into a computer. That means the nature of this knowledge is not as elegant as like Newton's Laws of Motion or you cannot write an algorithm and programming to the computer.

Like very simple thing, the indicator lamp on any instrument should be above the switch. If it is not above the switch, obviously when you are switching on you will be covering the lamp and you would not immediately know whether it is switched on or not. It is a very simple practical constraint. Maybe an engineer routinely incorporates that but not when you first time design your equipment.

For example we had someone long back who is trying to put his heat sinks right on the front panel because he considers why not put it on the front panel. Heat sinks produce dissipate heat. Obviously they will be at high temperature and then you never put them on the front panel and burn your hand. It should obviously be at the back and adequately cooled with a fan or otherwise. So these are some practical constraints.

Another example the clearances that must be allowed between physical parts in an equipment for tools and hands to reach different parts. For example when you are trying to design a new equipment, first thing is you should be able to readily open that when there is a fault. Once you open that by opening the top panel or back panel and whatever it is, then you should be able to reach all parts by hand or using tools.

If you cannot, that equipment cannot be repaired or it has to be so totally dismantled it becomes very expensive to service the equipment or maintain the equipment. There can be another practical constraint the design should be completed within two months. When you look at this piece of knowledge, practical constraint, it does not nicely fit with the kind of concepts that we deal with, conceptual knowledge we deal with in engineering science subjects.

What does it translate to when you have within two months, which means you have to design something with components and devices and technologies that are readily accessible, not necessarily something that is available in another country, it will take lot of time to access that. So this kind of constraint will actually translate into the way you would design a piece of equipment in a given situation.

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Now comes yet another kind of somewhat way compared to other science subjects called Design Instrumentalities. First thing is any engineering activity is a group activity. No single person will ever be able to perform a complete engineering activity. A group of people will work together.

They will share the work. There will be a leader for that and there are constraints in terms of financial and human resources and access to technologies.

So in such situation if one is operating, the design instrumentality refers to procedural knowledge including the procedures, way of thinking and judgmental skills by which it is done. Some examples: top-down approach to design of a product. That is whenever you design a product you should do top-down approach not bottoms up. That is a design instrumentality. And the other one is how do you want to phase the development of a product.

You do not want to approach all aspects of the design simultaneously. You want to phase. That is a very normal process. And that kind of experience should be given to the student. Phasing of solving any problem. Structuring of an electronic product. Before I design the actual circuits and all the element subsystems of that, I must be able to structure the product mentally or draw pictures or render the product the way I am visualizing.

For example something called design walkthroughs is a part of most of the software product development these days. That is somebody else walks through your design and gives his comments. For example another design instrumentality, still of a different quality, identify all members of the team early on and include every member in the group communications from the outset. That is a process, a procedure that you will follow for the team to be effective, okay.

So as you can see these four categories of engineering knowledge namely fundamental design concepts, criteria and specifications, practical constraints and design instrumentalities, they have to be incorporated right from the beginning in several courses in an engineering program. If you do not, you are not training somebody as an engineer.

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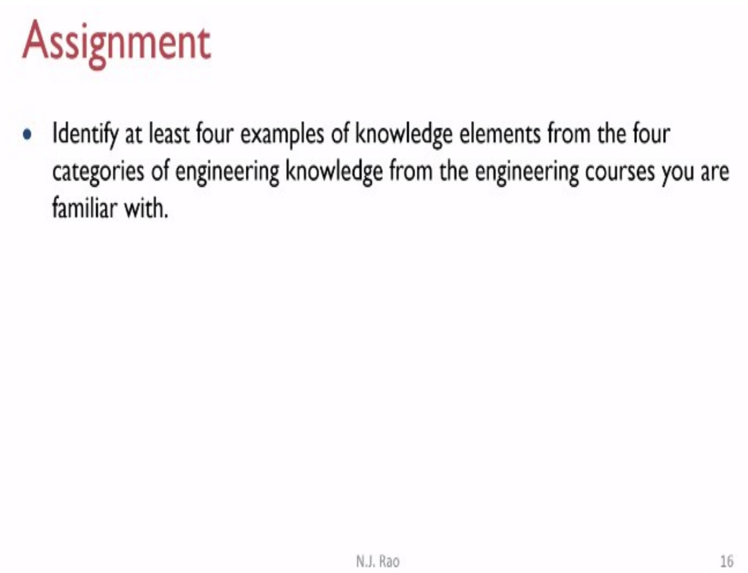

So now let us look at the kind of assignment that you we would like you to do. Identify at least four examples of knowledge elements from the four categories of engineering knowledge from the engineering courses you are familiar with. Just identify the knowledge elements. It could be just each element can be described in two, three words. But you have to think in terms of what is the relevant engineering knowledge that you want the student to be aware of.

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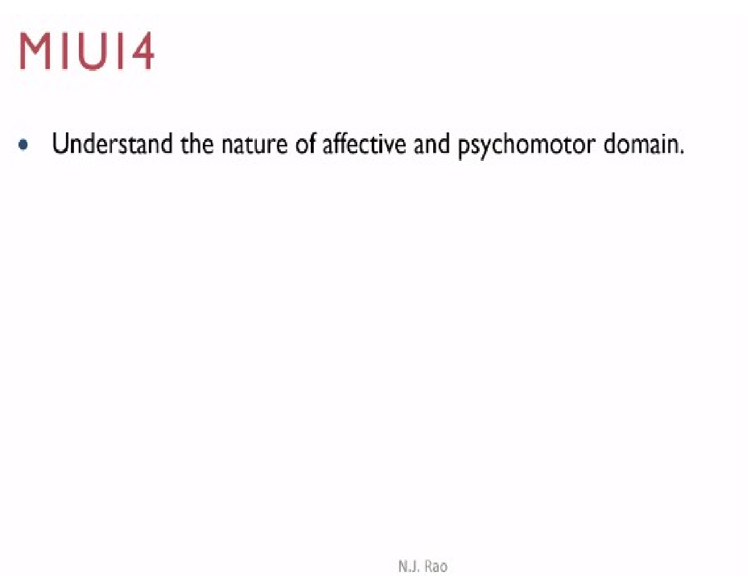

Okay, the next unit we will look at continuing with our taxonomy of learning. We will spend briefly in understanding the nature of affective and psychomotor domain but we would not be though affective domain is very very important, we still do not have adequate knowledge how to integrate that into our regular instruction. While we are aware of its importance or dominant role, but we can only adopt our intuitive methods right now. But we will still present a brief overview of both affective and psychomotor domain. Thank you very much for your attention.