Introduction to Research
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Lecture - 23
Creativity in Research - Part 3

Look at this velcro.

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All of you know Velcro®, which is used for BP meter, some times it is there in watches and all that. So, George de Mestral's observation of how cockleburs - a kind of plant - it got attached to his jeans pant; it was a constant nuisance. He was always trying to remove it. Then he said - can I invent a new product which can make use of this? And, can I convert the nuisance into a useful product? That's how the Velcro® came; this is a great… this is a great instance of creativity.

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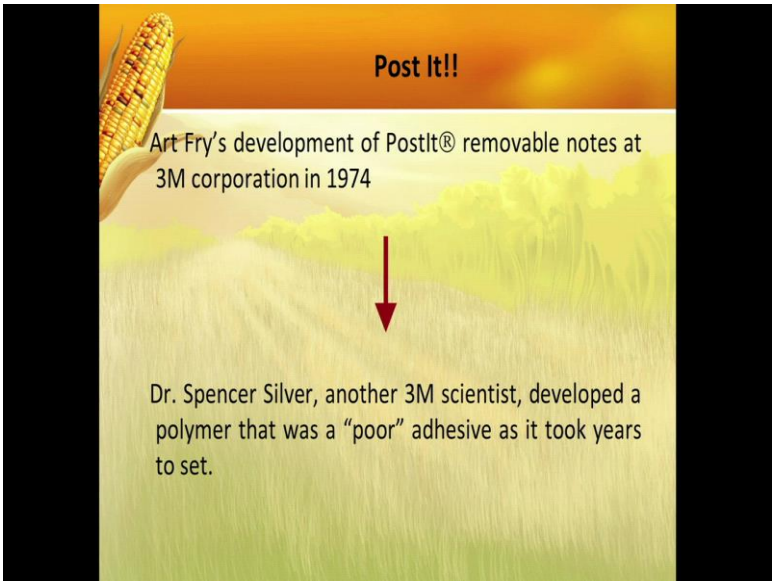

Next, post it okay. You know the PostIt®, right? The bookmark; the removable bookmark which comes in various colors, and shapes, and sizes okay. So, Art Fry developed this PostIt® in 3M Corporation, in the US, in 1974. Doctor Spencer Silver - another 3M scientist - developed a polymer that was a poor adhesive; it is considered as failure because all polymers were considered to be like… - it was successful only with like Fevicol, they said two elephants will attach and that is the advertisement - but this was failure because it is not permanently attaching. Art Fry said, if something is there which attaches, but does not attach permanently, I can use it as a bookmark; I can put it on files, and I can write some notes - please clear this file and all; then, it can be removed whenever the job is over. It has become such a big, successful office product - PostIt®.

By ignoring conventional wisdom that any adhesive has to permanently set, Art Fry deviated from conventional wisdom and got a successful office product okay. This is also an instance of creativity.

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There are several other instances, for example, the Japanese bullet trains; the bullet trains travel at a very high velocities - 250 kilometers per hour and all that; whenever they are entering a city, whenever they are entering a station, that tunneling effect is there, they used to produce a lot of noise, and all the people close to station, they complained that the bullet trains are generating excessive noise, and in Japanese, every 10 minutes there is a bullet train okay, and then, JR - Japanese Railway - started working on this. They figured out how the kingfisher catches it's prey okay, and then, without any noise, if it makes a noise, the fish will escape. So, it it dives and this thing such that it makes very little noise. So, they figured out the aero dynamic body, the precision all, this; so, it is bio-inspired, bio-inspired engineering and the Japanese Railway figured out a way by which now the nose cone of the new generation Shinkansen or the bullet train, it is shaped like the beak of a kingfisher. Once they did it, the noise considerably reduced; no complaints from the residents. So, you can, so, you can draw inspiration from nature also alright okay.

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Flow and creativity. Flow is a concept in psychology; this was first proposed by Professor Mihaly Csikszentmihalyi; Professor Mihaly Csikszentmihalyi - very difficult name to pronounce. He is a professor of Psychology, University of Chicago. So, it is like your flow is, basically, like the unknown rider, and you forgot your Bournvita; that is basically then you are in flow okay.So let's leave all this.

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So, let us leave all this.

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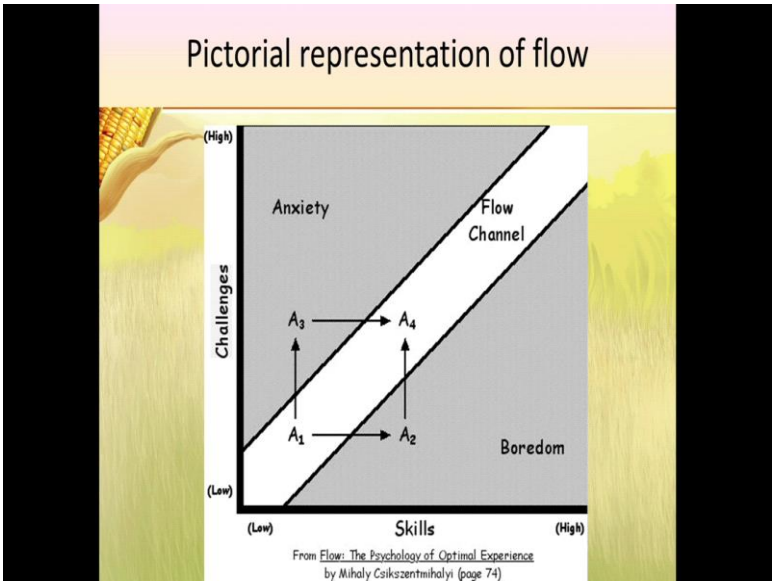

So, this is a flow curve. If you see, y-axis is challenge and x-axis is skill; y-axis is basically the difficulty level in the problem you are pursuing; pursuing x-axis is your skill. If the skill is very high, if the skill is very high and the challenge is very low, you will feel bored; that is in the grey color. If the skill is very low and your challenge is very high, if your challenge is very, very high, then it can happen to you, it can happen to you in your Ph.D. problem also, then you will be highly anxious, but if your skill and challenge are in balance, you are in that white path which is called the flow channel, and there is an exact matching of challenge and skill, the best thing you will come out, and you will enjoy what you are doing; this is the basically the Flow Theory okay.

Let us consider that a ten-year-old, a ten-year-old boy, wants to learn tennis. He is at the level A one. His skill is very low, and his challenge is very low, because first few days the coach will ask him to play against the wall. He will tell him what is the racket, what is a ball, what is the height of the net, what is the height of the net at which you play and all that, and then he will start returning this serve and all, that he will learn. Slowly, his skill will improve, and he will go from A one to A two. After two months also if the coach will say's that you will play against the wall, then his skill is very high, his

challenge is very low, he will get bored, and he may drop off from tennis. Other possibility is he will tell his coach, no, no, I want my challenge to increase, then he will ask him to play against the school champion then suddenly or he may ask him to play against another student, then suddenly his challenge is increased to A four, and he finds that there is the sheer unpredictability of another human being playing as against the wall, and the variety of new things which he is learning because he is playing against somebody else makes the whole process of playing tennis more exciting and more enjoyable. Then, at A four he is very happy, and then, you cannot stay happy at that A four for a long time, again he will learn, he will go to A five or A six. Then, he will get bored; he will start playing inter-school, intra-school, inter-district, national and this thing and go on.

Let's go to the other end. The first day itself the teacher asked him to play against the school champion. So, from A one suddenly it is increased to A three. A three, the challenge is very high, because the other fellow is smashing left and right, he doesn't even know, this fellow gets scared, he will tell – mummy, from tomorrow I am not going to tennis. Like, some coaches will just put the child into the swimming pool, into the water; that is a last day the child will go to swimming pool. Next day onwards…Sometimes, it happens, sometimes, you know, they just throw out the child into the swimming pool okay. So, the challenge is very high in A three. So, he may either drop from tennis or he will ask his coach - how that fellow is playing like that, and the coach will say, if you have to play like that fellow, you have to practice. So, you go from A three to A four. So, that route also A three to A four he will go. Then A three to A four

Here the funda is you cannot stay in A four for a long time; you will either learn or somebody will… suddenly your challenge will increase. In an office, the challenge will increase because your boss will give you something, which will make it very difficult for you to work or you keep on learning and it becomes something is boring for you. Only when, so, therefore, life itself will have situations where you are either at the border of the boredom or anxiety, in between boredom and anxiety there is a narrow window, you should navigate life in such a way that your challenge and skill are matched, so that you are happy. Only if you are in that, out of the grey region, you will be happy. Is it okay? This is a theory by Csikszentmihalyi okay.

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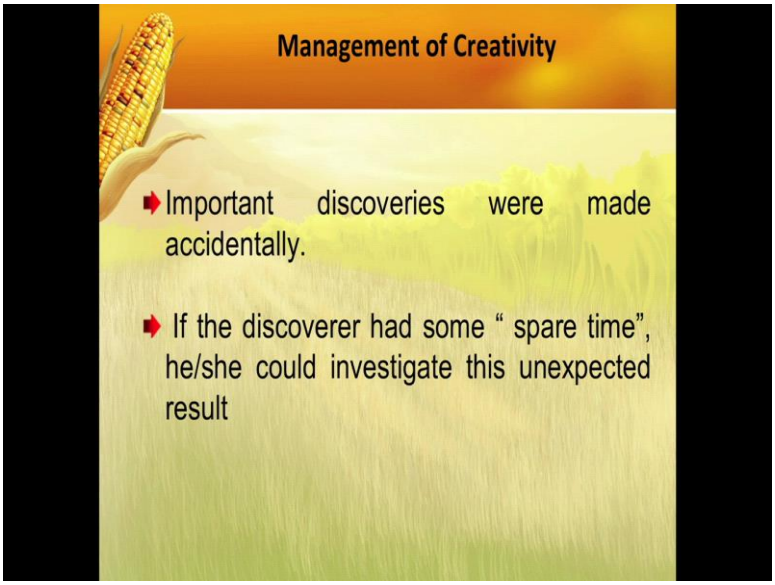

Management of creativity. Suppose, you have too much creativity - how to manage? Now we have to answer a question, no? Okay so, important discoveries were made accidentally. If the discoverer was given more time, and then, he or she should, could investigate this unexpected result. Therefore, your boss or guide or whatever, if you are pursuing something, as advisers we should give okay, even though it may not be central to your work, we will say, ok, another one or two months we will go, it doesn't matter; you try this line; suddenly, if something exciting comes, then we can, we can pursue further in that line; is that ok? That's what I am trying to say.

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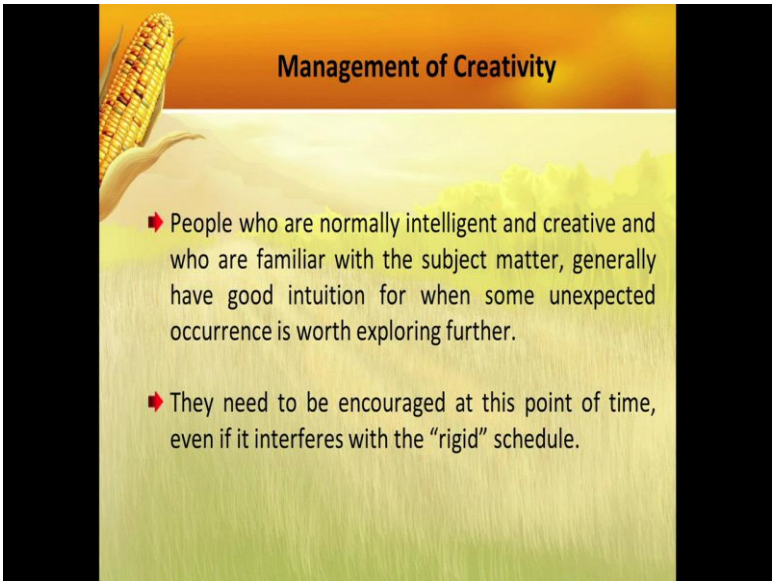

People who are normally intelligent, and creative, and who are familiar with subject matter, we have generally a good idea on when some idea is worth pursuing. You may get lot of brain waves, but if you are intelligent and smart, then you will know that, ok, some many ideas come, this idea is not very good. So, you will filter out yourself which one is worth pursuing and which one is not okay. And then, finally, you have come to conclusion that this is worth pursuing; then your boss or who ever it is, must encourage you and give you sometime to pursue this.

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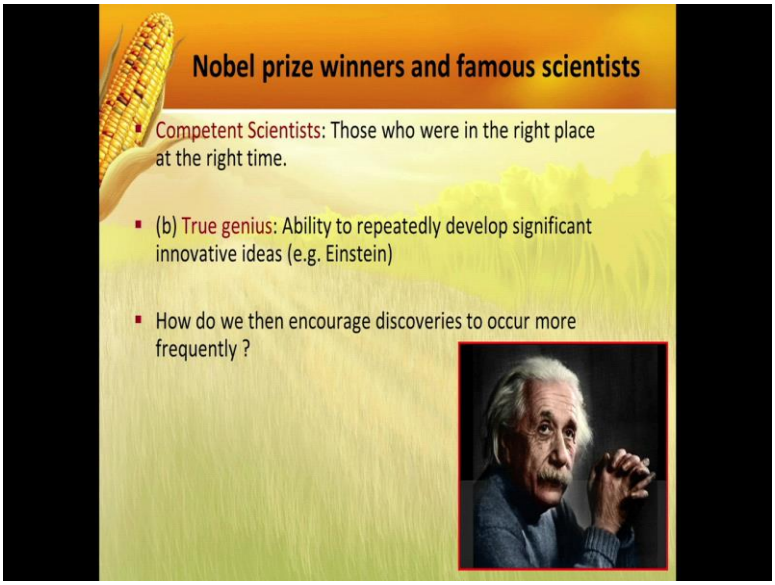

Let us look at the lives of Nobel prize winners and famous scientists. Competent scientists. There are two types of scientists: competent scientists - those who were in the right place at the right time, and true genius. I am not saying that those who were in the right place, in the right time, are not great people or whatever, they are also very competent, but a true genius is one who repeatedly generates lot of new ideas; Albert Einstein was one. If you look at these lives of these scientists, let us see, let us try to figure out, how can we encourage discoveries to occur more frequently.

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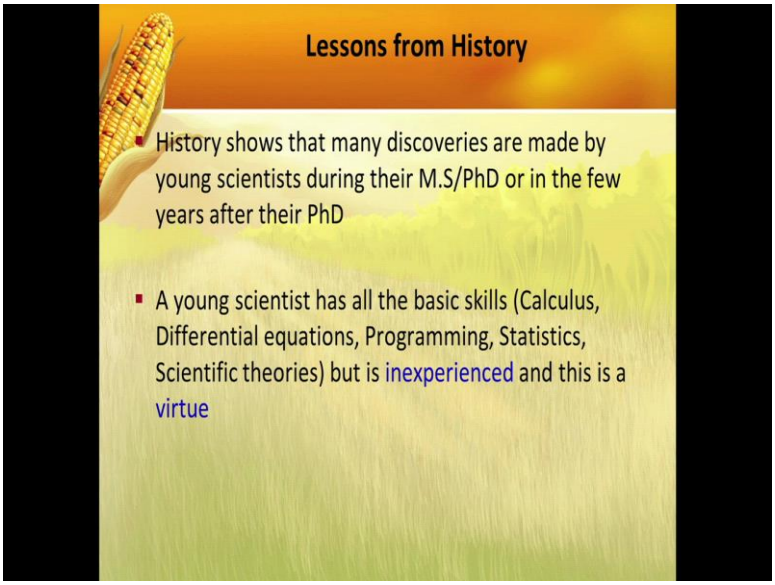

History shows that lot of discoveries are made by young scientists who during the MS or Ph.D. or in first the few years of the Ph.D. they found something remarkable okay. So, a young scientist has all the skill calculus, programming okay, measurement techniques, whatever, differential equations, statistics, and scientific theories and so on, and but he doesn't have a baggage - he doesn't have a reputation, that he is not scared of failure, but if a professor or somebody who has worked in a field, who is already established, he is worried - what will other people think when you write this thing. So, generally, you tend to get close, then you will say, no, no, I have seen, I have seen, I know from my experience this will not work, this will not work, this will not work, this will not work okay. So, being inexperienced, a young scientist is fearless; a young scientist is fearless, then we should encourage him or her at that point in time. When someone has worked, or lived in an environment for more than ten years he or she tends to be less curious because of familiarity.

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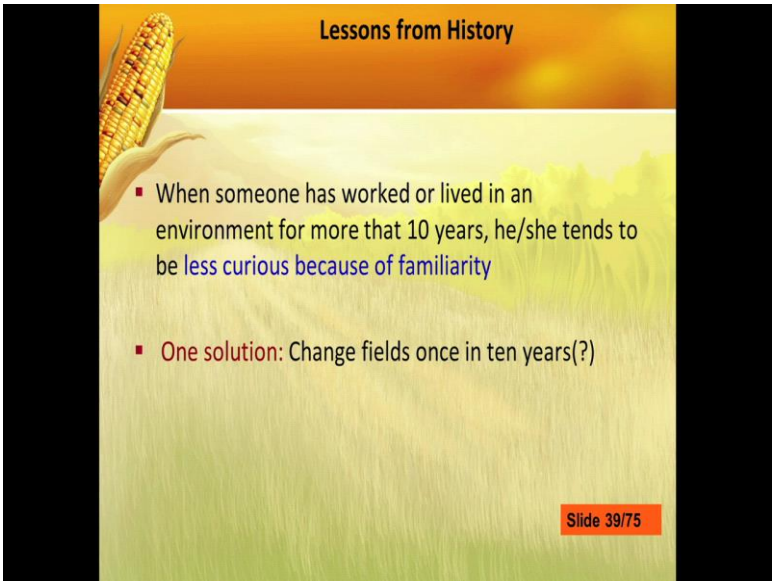

So, generally okay, so, one solution is change fields once in ten years. Many people have done that. So, I just talked about timelessness, and flow, and all that; therefore, I am putting this slide number also. So that one way of how to find out in a class that the people are in flow is - how many times students looked at the watch okay.

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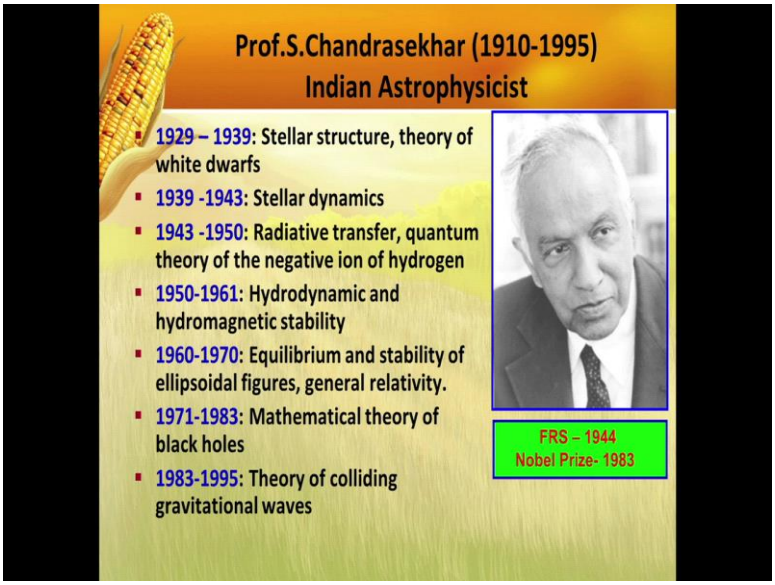

Professor Subramanium Chandrasekhar, Nobel Laureate, 1983. He got the Nobel prize. We can see that every ten years he has changed the field; 1929 to 1939 - Theory of white dwarfs, theory structure of stars; 1939 to 1943 - Stellar dynamics; 1960 to 1970 - Stability of ellipsoidal figures; 1971 to 1983 - Mathematical theory of black holes; and 1983 to 1995 - Theory of colliding gravitational waves. Every ten years he has worked in a new field, wrote a book, conquered the field, and then, moved on okay. Don't get stuck to what you learned in Ph.D. throughout your life. Then, the contribution will become marginal then, you should improve okay.

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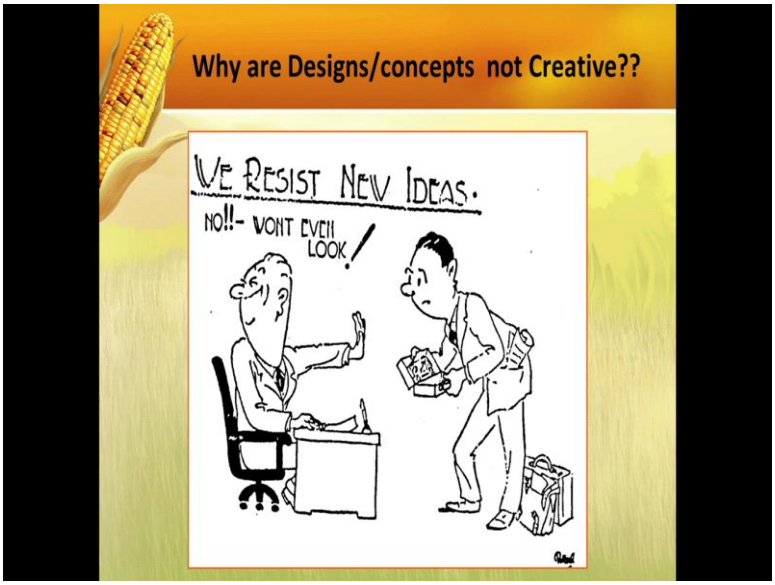

Why are designs, concepts, and all these things not creative? Why is not there much creativity? Now, that we have seen all the theories and all that – why? Now, let's try to the answer the questions - why are designs or concepts not creative? We resist new ideas; no, no, this will not work.

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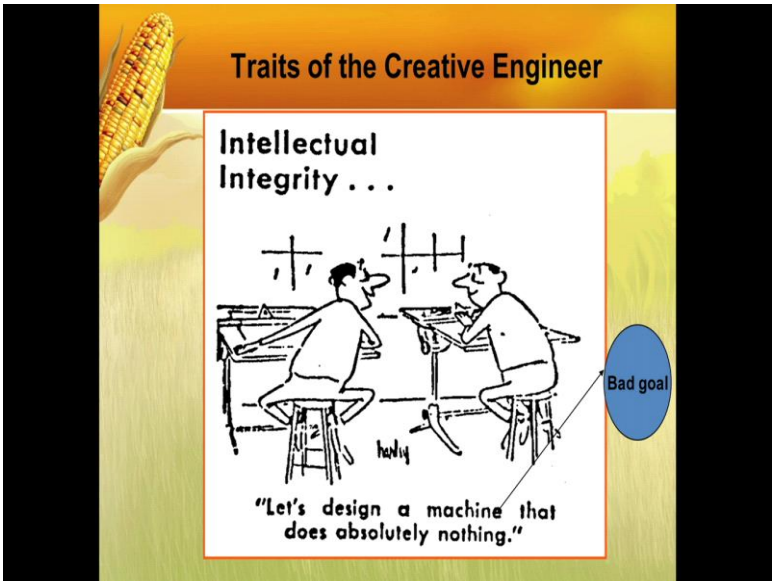

And, sometimes, integrity is not there - this fellow says, let us design a machine that does absolutely nothing. That is a very bad goal okay.

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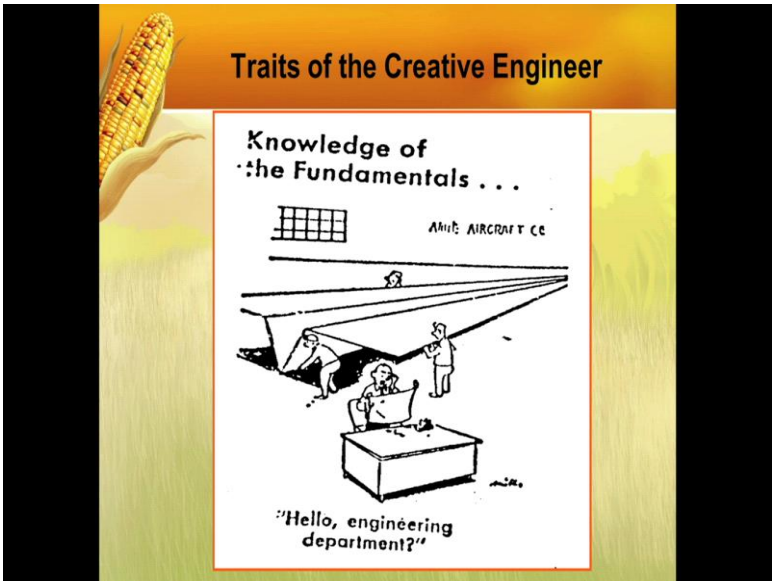

Knowledge of the fundamentals. So, he is in the aircraft wing division. This is like the rocket which is thrown at teachers. So, then, hello engineering department, we should

know that this is not the way to make a wing okay for an airplane.

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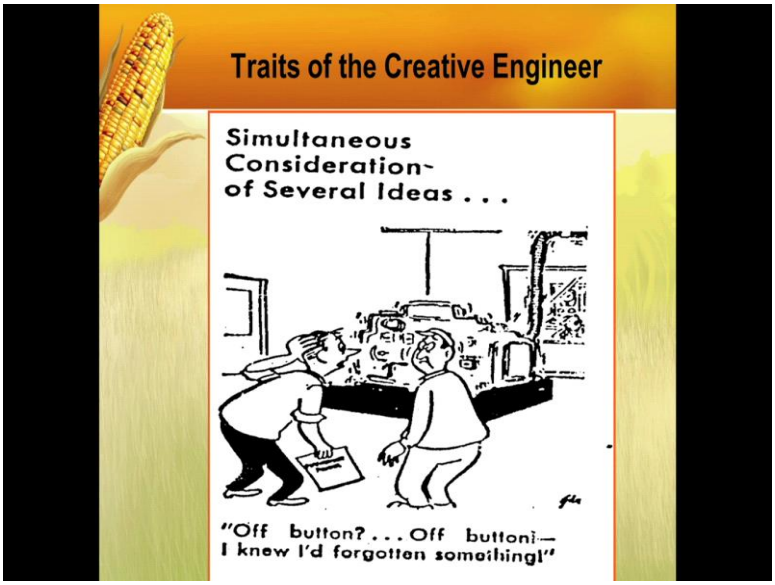

Simultaneous consideration of several ideas. They built a such a wonderful machine, but they forgot the On Off switch. They do not know how to switch off this okay. In your, under graduate lab, the engines lab and all that, four people will do the experiment; only one fellow will do; all other three fellows will be chatting okay; only that fellow will know that in the Kirloskar engine where is On Off switch. So, in my under graduate days, in the Guindy Engineering College, the professor, in the viva, he will say, where is the On Off switch for the Kirloskar engine; he will find out who was chatting away and who did it? So, it will be there some where behind na, yes okay. So, this On Off switch is very important.

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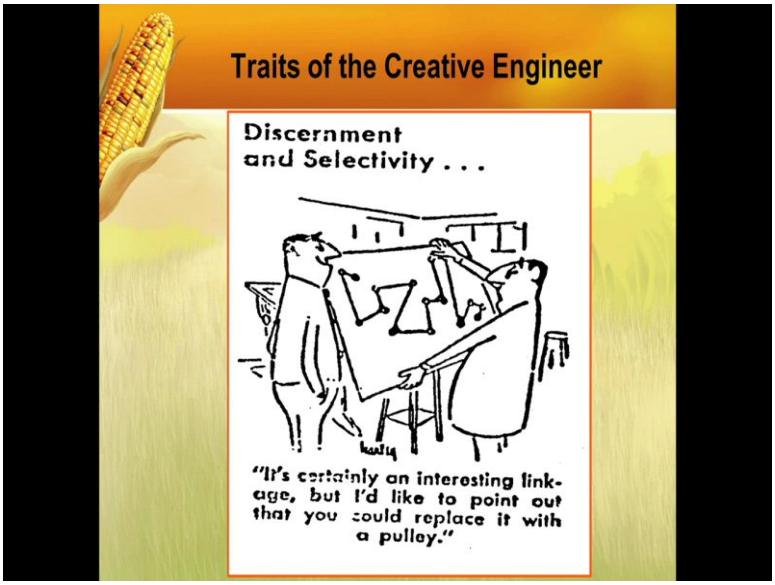

Then, discernment and selectivity. We have something called Contraption in our Shastra, in our IIT Tech Fest. That is to make a simple thing more complicated. So, if a pulley can do a job, there is no need to put a complicated arrangement like this. Therefore, simplicity is very important. You should try to make things as simple as possible. Edward de Bono okay, who is a protagonist of this lateral thinking, he is written a 500-page book on simplicity, how society has become very, very complex, how do decomplexify; it is a book on simplicity, Edward de Bono okay.

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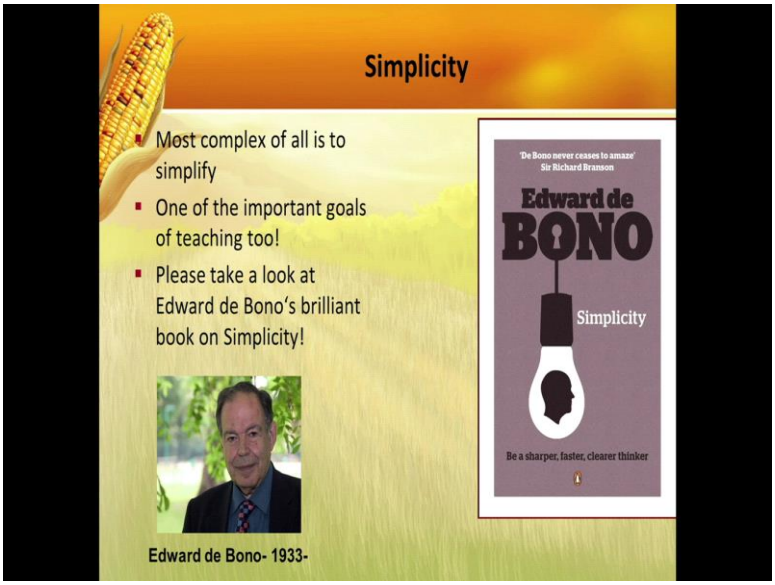

So, he says the most complex of all goals is to simplify; that is also one of the important things in teaching. We should make it very, very simple, that to such an extent, that somebody cannot make it any simpler. Then his brilliant book on simplicity you can buy; it is available; you can buy it on Flipkart or Amazon.

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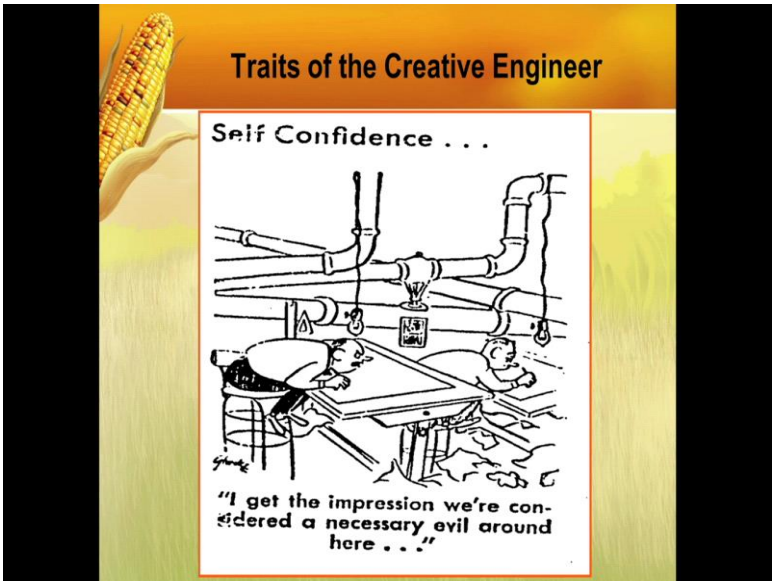

Self confidence. You should not start out, I get the impression that we are considered a necessary evil. I get an impression that I am unfit for research. You just leave. Then, you should have a chat with somebody who is very enthusiastic and this thing right. Do remember that 10,000-hour rule; if you spend 10,000 hours, you have it already. How many people have already done their Masters? How many people have cleared the comprehensive viva. You come up to this stage, then you will do the other things also. That confidence you should have. All of us go through that this thing, but that when you go through this, you should not think that is permanent okay.

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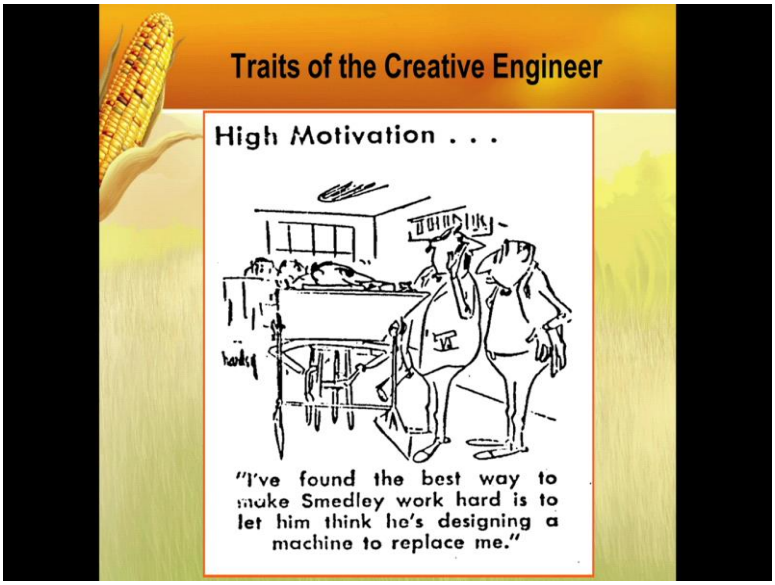

High motivation. I found that the best way to make Smedley work, work hard, is to let him know he is designing a machine to replace me. That's the boss telling his subordinates, you design a machine which will replace me; then, it gives so much kick and energy to the subordinate okay.

Constructive Nonconformity. You should not, just because you keep four pencils or you have a haircut like this, you are different. There is no point in just looking different; you should do things which are genuinely different okay.

Ability to think in images. We should be… your Autocad, Three-D, these things… that is

why drawing is the language of engineers. So, we should be good in that.

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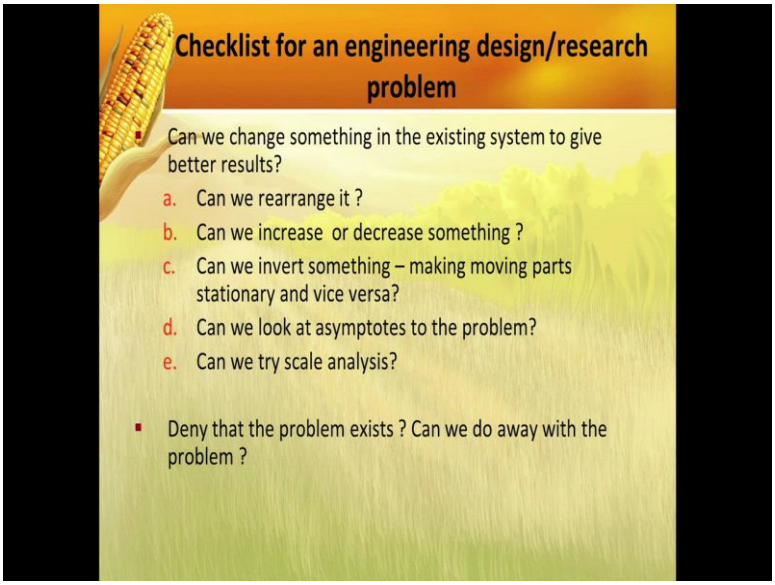

What is a checklist for an engineering design problem? Can we change something in the existing system to give better results? Start asking these questions in your research problem. Can we rearrange something? Can we increase or decrease something? Can we make moving parts stationary and vice versa? Can we look at asymptotes to the problem? If you are working, can I look at asymptotes? Can you look at Reynold's number tending to zero? Can I look at Reynold's number Ten into infinity? Can you look at g r by r e square tending to zero; g r by r e square is equal to Ten into infinity; epsilon tending to zero; thermal conductivity tending to zero; thermal conductivity tending to infinity, and then work out some maths, and find out some asymptotes, which can be used to benchmark your solution. Can we just work with paper and pencil instead of always going to the computer? You should ask these questions okay.

Can we do scale analysis? Can we look at approximal scale? So, how much time it takes for cooling? How much time it takes? Can we look at approximate scale for what is the maximum efficiency of your collection? Actual collection efficiency divided by the maximum collection. Can we call it as a new parameter, new paradigm or something, whatever in your field, and the deny that the problem exists? Ok, it is too much; take

some ten days off; don't work on it; then come back; you may get a solution.

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What similar problems exist in other fields? Analogy method. We use that analogy method. Electrical resistance network we used in conduction. Can we look at analogy? Can we look at how nature might have solved this? Nature, see, this called biomimitics, biomimicry, the genetic algorithms, ant colony optimization, bombardier beetle action, all these are inspired from nature. What prior solutions exist in other fields?

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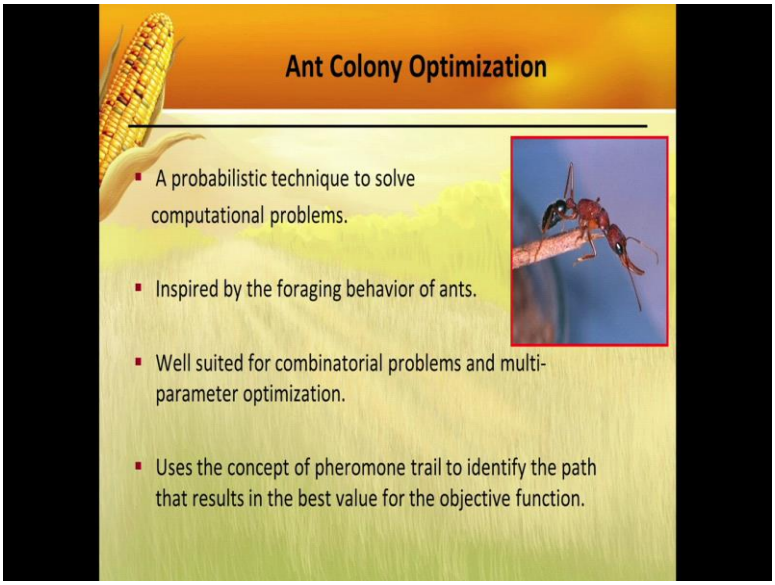

Ant colony optimization. It is a probabilistic technique to solve computational problems. It is inspired by foraging behavior of ants; foraging behavior means how they behave when they look for sugar or food. So, well suited for combinatorial problems okay. So, when the ants go in search of food, they find out the previous ants in which path they have gone. So, after the ant has taken the sugar, it will leave that… it will leave a chemical, what is called pheromone, which is like formaldehyde. So, out of the multiple paths, the paths of the other ants, the next ant which will follow, will look at the paths where the pheromone concentration is very high. So, like wise. So, automatically, it ignores paths where the concentration is low; therefore, this can be used for a minimization function. So, this, in operation research, they will use this to solve the travelling salesman problem and so on okay.

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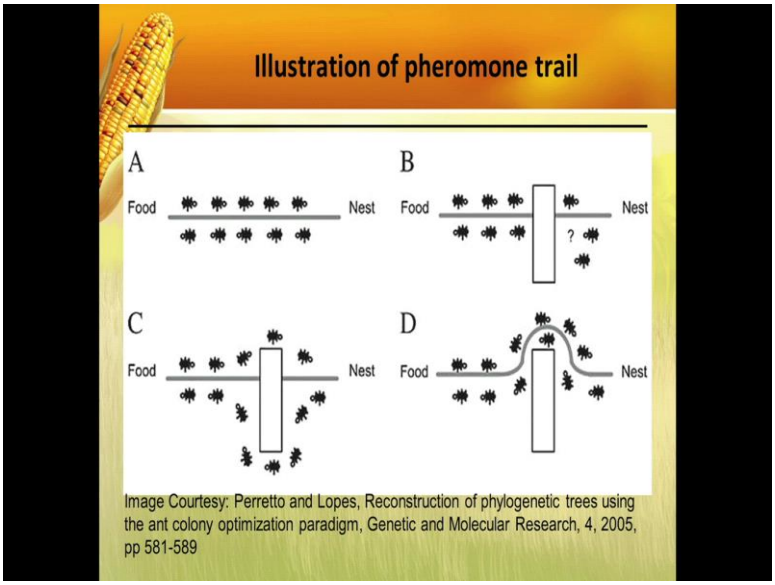

In optimization engineering, we are using this in regular optimization problems also. So, this can be used to find out the best value of objective function. So, you try this experiment. If ants the are… if there some sugar, ants are coming, you place an obstruction, then after sometime the ants will figure out the least path - the shortest path - automatically. So, we can see, you can keep obstruction, then first it will get confused, in C it is getting confused, but in D it is again choosing the shortest path. So, you can develop an algorithm based on this okay. So, that pheromone concentration; assume an initial pheromone concentration; the pheromone concentration in time is e to the power of minus pheromone concentration at this thing, you need to divide by pheromone concentration at time t equal to t naught, and then you can develop an algorithm. One of my students, some years ago, did this. So, as a B.Tech project. So, this is the… basically you see after the obstruction it becomes clear, first it becomes unsettled, then it becomes clear.

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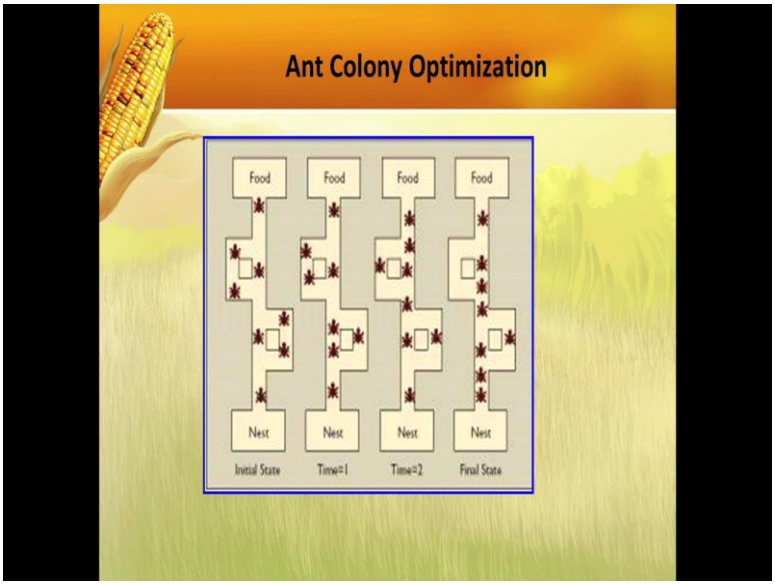

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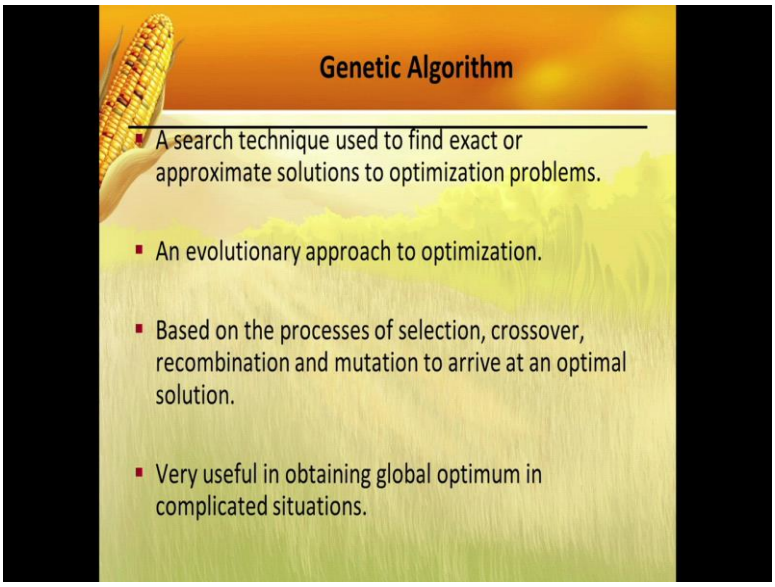

Genetic algorithm. Genetic algorithm basically mimics the process of evolution. Evolution can be treated as an optimizing process. Best parents mate, and get, and produce the best children. From the best children, new sets of parents are created, like that… If you have multiple solutions, you find out which solution gives satisfies objective function, maximizes your objective function. In the case of a maximization

problem, convert your variables into zeros and ones, mix and match chromosomes in similar to genetics, and then, produce new children, check for that fitness – that's objective function mix and match. Randomly, alter some bits - that is mutation - and then proceed. So, you are getting inspired by nature. So, genetical algorithm is a very powerful tool now used in optimization okay.

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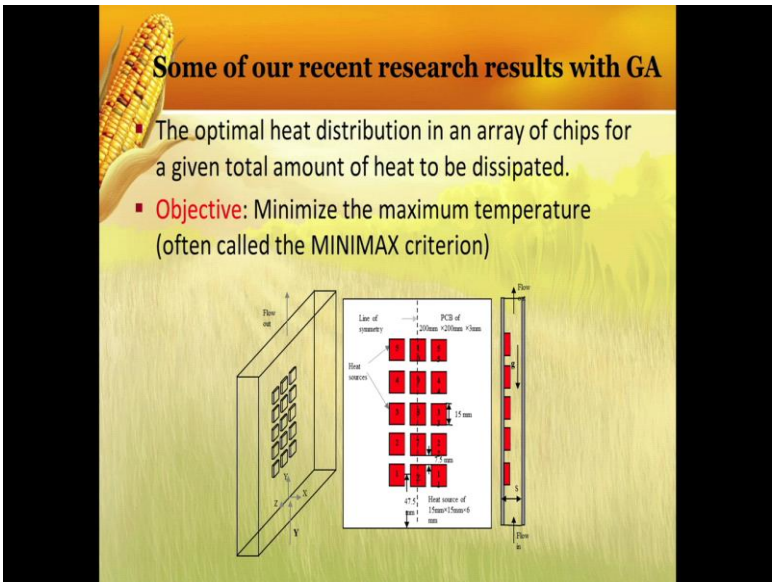

So, some of our research, for example, there are 15 chips which are generating heat. If the total is 15 watts, how will I distribute these 15 watts among these chips, such that the maximum temperature is minimized? This is called a minimax problem. So, this is a fundamental problem in electronic cooling. So, the base line could be, you put one watt to all the 15 and find out what is the maximum temperature. Then, you do your genetic algorithm, what have you used up whatever optimization, and find out what is the best, and compare to this case where your got uniform one watt for everything - how much is the temperature decreased okay? That is the benchmark okay.

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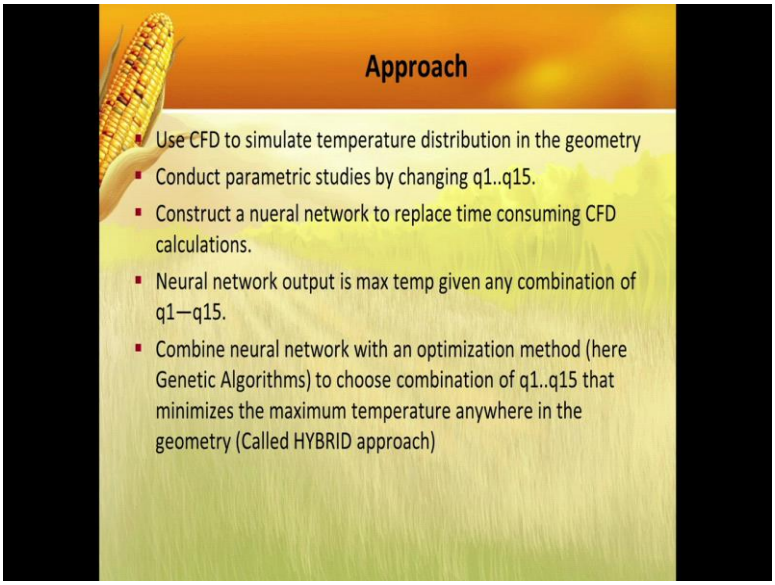

So, approach is, use CFD to solve this, and then, give different combinations of q1 to q15, generate a neural network, because the CFD takes a lot of time, it is computationally more involving, more involved. So, generate a neural network, which is called a surrogate model or a fast forward model. Then, whenever the optimization genetic algorithm wants solutions, want what solution means, if I give q1 to q15, what is t1 to t15? That the neural network will give. Use this neural network to drive your optimization engine or genetic algorithm. Try various combinations of q1, q2, q3, to q15; find out which combination of q1, q2, q15, gives minimum of the t1 to t15, subject to the condition that q1 plus q2 to sigma q is equal to 15 watts, 10 watts, 20 watts, whatever has been assigned by you. Is it okay. It is the classic optimization problem; use genetic algorithm.

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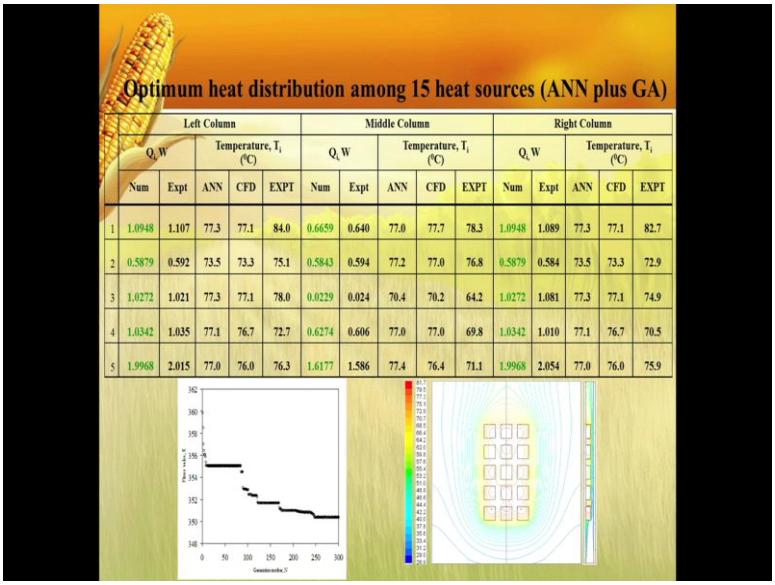

	Left Column					Middle Column					Right Column				
	Q_i W		Temperature, T_i (°C)			Q_i W		Temperature, T_i (°C)			Q_i W		Temperature, T_i (°C)		
	Num	Expt	ANN	CFD	EXPT	Num	Expt	ANN	CFD	EXPT	Num	Expt	ANN	CFD	EXPT
1	1.0948	1.107	77.3	77.1	84.0	0.6659	0.640	77.0	77.7	78.3	1.0948	1.089	77.3	77.1	82.7
2	0.5879	0.592	73.5	73.3	75.1	0.5843	0.594	77.2	77.0	76.8	0.5879	0.584	73.5	73.3	72.9
3	1.0272	1.021	77.3	77.1	78.0	0.0229	0.024	70.4	70.2	64.2	1.0272	1.081	77.3	77.1	74.9
4	1.0342	1.035	77.1	76.7	72.7	0.6274	0.606	77.0	77.0	69.8	1.0342	1.010	77.1	76.7	70.5
5	1.9968	2.015	77.0	76.0	76.3	1.6177	1.586	77.4	76.4	71.1	1.9968	2.054	77.0	76.0	75.9

So, you can… So, you can see that.

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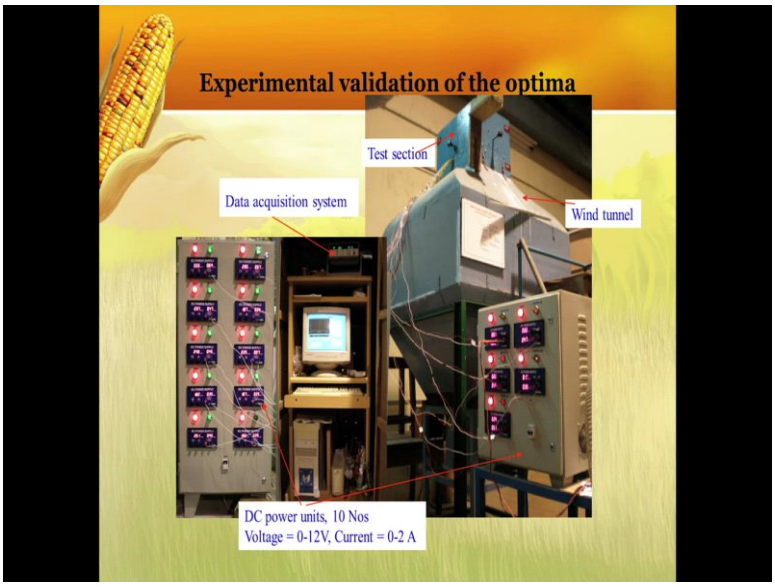

So you can see that finally, the optimum. So, you can generate the solution from ANN - artificial neural network; you can generate from CFD, and you can, finally, confirm, we confirmed with the experiments, we get within an error of 7 degrees; you get within an

error of 7 degrees. You can see that the q, the q is not one on everything. So, for some heater it is 0.5 watts, for some heater it is 1.091, for some heater it is 2 watts and so on. So, that distribution gives you, that gives you, that gives you minimax. Therefore, putting one in all the fifteen which is a trivial thing, which somebody will say no, no, I will know by this thing, I will know by dharshana, I will know all that - it is not possible. You have to go through this; you have to go through this optimization procedure to achieve this. Finally, after we obtain the optimum configuration, you have seen this wind tunnel in our laboratory, so we put that all this - there are 15 DC power supplies - we energize q1 to q15, gave what was experimentally, what was determined by the optimum or by the optimization program, and we figured out, that finally, the experiment gave less than 10 percent error. So, the optimum is confirmed by or validated experimentally.

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Check list. Can we solve a similar problem? Checklist for a research problem okay or a creative design problem. Deny a natural law. Can you ignore g and proceed and see what happens? Try fantasy. Use brain storming - discuss with your friends in the coffee table. Breakup the problem into essential sub problems and start attacking only the sub problems or just give up for a week or ten days and then get back okay.

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What are the key road blocks? Basically, fixity or mental block. I cannot solve this it is, so difficult. You have to get rid of that mental block. Analogy is a very good aid. So, for example, ant colony and genetic algorithm analogy kingfisher analogy to nature, electric analogy resistantant network. So, keep your ears and eyes wide open. If you look at lot of journals - what are the electrical people doing? ANN and all this computer science people are doing. So, you have to look at some computer science journal. Artificial intelligence, some ideas from there you quickly put it to heat transfer and your first paper, your paper will become highly cited. So, you should know what other people are doing also. Instead of just seeing, you are looking always at what heat transfer people are doing, what solar people are doing; instead of that, you should also look at… get some best ideas from other fields and apply it to our field okay.

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Summary. The inventive/creative phase of the design research process. The inventive/creative phase of the design or research process is the key where we generate ideas and concepts to solve the problem. Once you generate the concept or idea to solve the problem, then the next stage is you will either write a program or you will develop an experimental setup and all these. So, the generation of ideas and concepts is where the creativity is involved. After that, after it is generated and all that, you build your experimental setup, then you get bogged down with details; then you look for a mechanic, you look for a technician, you look for those things, you look for a dark room, and then, you will do ventilated, this thing, night I don't want temperature to change, but the quality of whatever you get, whatever you get the usefulness or not, the creativity or not, the innovativeness or not, depends on the quality of your ideas. This experiment will give this.

According to you it is dharma, it will give the result, but whether it is useful or not depends on what is the quality of the, quality of the… what are the ideas behind the setup itself? You get what I am saying? Whether that itself is worth or not, that's where the idea generation is important okay. So, the quality of ideas is very, very important. That's why we need to be more creative. So, therefore, creativity, what is creativity ultimately? All the elements are already in your mind; this is the combination of all these things and

something comes out. As they say, a good teacher is somebody, a teacher is one who figures out what is already there in the students mind and allows that to come out. We cannot implant new things into this. We can only help whatever is there to come out okay.

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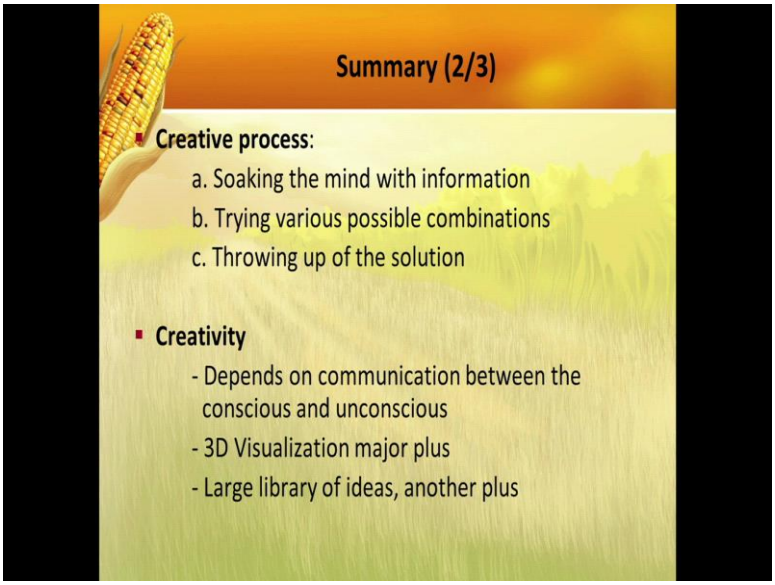

The creative process is you soak the mind with information. You try various combinations, and then, throwing up of the solution, and then, you say: this will be my experimental design; this will be the governing equation; this will be the problem I will solve. So, the creativity depends on the communication between conscious, again there is a typo, it's not unconscious, subconscious; there is a constant dialogue; this dialogue may take place when you are sleeping, in dream also it may come, in the dream also sometimes it may come, sometimes the dream also the computer go to line 640 I didn't divid it by 2; morning when we are there, at nine 'o' clock only the computer center will open; eight 'o' clock, eight thirty you will go, you will change, but you put that 2 also it may not work, that's a different matter, but atleast you know that problem that I solved; line 620 problem, again you sleep, line 1424 that square root is not there okay, and then what do you it's not working, write statement, write statement, write. So, you keep on every two lines, you put write statement okay. You will have to go through this journey okay. Three D visualizaton is very important. Talking to others, developing your

scholarship, and then, large library of ideas, you should look at biographies, you should get inspired; you should have large library of ideas, where you are able to generate many ideas and pursue them okay.

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How to improve creativity? Start playing games or puzzles; have some hobbies which will release your imagination; write some poetry or maintain a daily journal, just maintain what all you have done everyday; read short stories; read poetry and biographies, it provokes your imagination; write, not write not journal paper, write about your experiences or something you dont have to show to others also, show it to only your close friends; you are going on a three day trip to some place, write it down on word and share it with somebody else. And then, experiencing the process. So, this I will skip; you want this? We will skip this.

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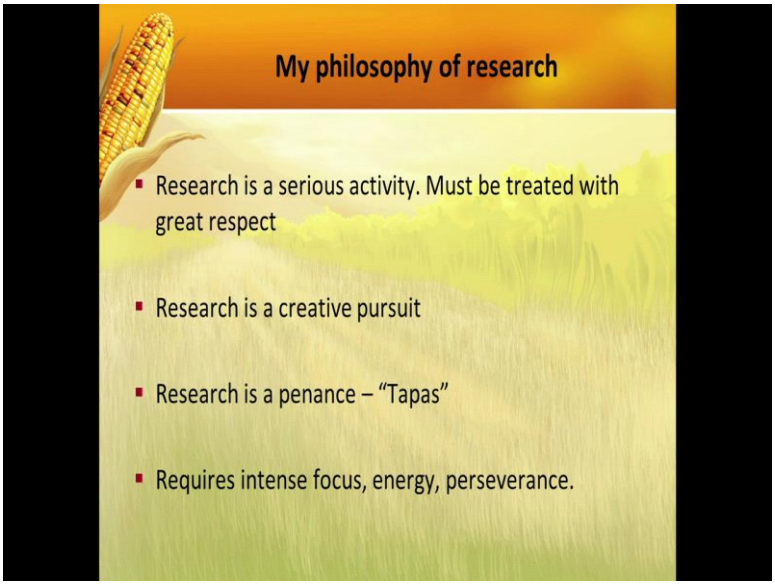

Okay, finally, research is a serious activity. It must be treated with great respect. It's a life long activity. It is a creative pursuit. So, it is a penance or tapas okay you have to keep doing it. It requires intense focus, energy; it doesn't mean that you cannot relax, you can relax, but generally just like a compass will always point towards true north, whenever there is no activity automatically the mind should come towards research. You allot some time, you want to do a sport, you want to jog, you want to walk, you want to play tennis, you want to watch a movie, all that is fine, but the compass left undisturbed it will come to true north. Mind must pursue that, within five years I want to do, that ten years I want to do that okay.

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Success in research is very difficult. Other people should tell whether your successful or not; we should not keep on talking. Time will decide whether you are successful or not. We have to freak out, we have to enjoy what we are doing; that's very important. So, the ultimate goal of any research is to get that immortal status; everybody wants to know - will I become another Prandtl? It's very doubtful; you may not become, but at least the goal is there. Will everybody talk about me, just like they are talking about Prandtl? 1905 Prandtl's Boundary Layer Theory; 2016 also any professor going to the class Prandtl's Boundary Layer Theory. We don't know what you do; we may not even come to one percent or half a percent of that, but inside you have - can I become the next Prandtl? Okay. It's good to have that goal and proceed okay. You want to attain that immortal status okay; you call it as anantha.

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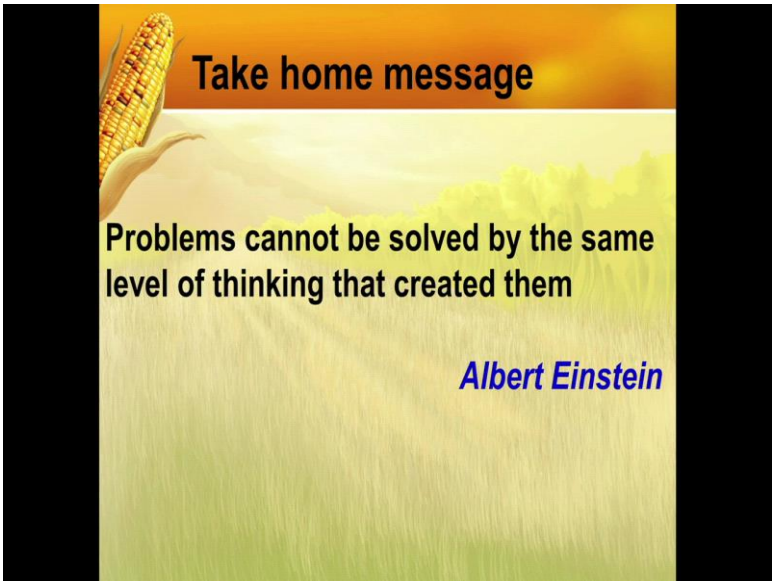

Take home message. Problems cannot be solved by the same level of thinking that created them okay. So, you require a higher level of thinking to solve problems.

Thank you very much.