Introduction to Research
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Lecture- 21
Creativity in Research - Part 1

Okay so, good morning. Welcome to this MOOC course on Introduction to Research. So, my name is Balaji. I am a professor in the Department of Mechanical Engineering. I specialize in optimization, and e-transfer, and numerical weather prediction. So, these two hours we will talk about Creativity in Research. Creativity is often misunderstood or not understood properly; particularly, in engineering, generally people have a feeling that creativity is very less. So, the moment you talk about creativity, you talk about arts, you talk about movies, you talk about music and so on, but actually there's a lot of creativity in engineering also. And in research, we will have to see how we can use these principles of creativity which have been developed for the past few centuries, so that we can make our research more exciting and meaningful alright.

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So, the outline of the two lectures will be as follows: first, we will see what are the attributes of becoming a fully professional researcher. Then, we look at Sternberg's theory of creativity. He is a professor in Yale university in US. Then, we look at the 10,000-hour rule by Herbert

Simon, a Nobel Laureate. Then, what is the role of stress in research. All of you are doing research; so, obviously, stress is an integral part of research. So, we need to be stressed, but we should not be too much stressed. So, Peter Medawar, Nobel Laureate in medicine, in 1960 he got the Nobel prize. So, his ideas on research problems. Then, what are the lessons we learned from lives of Nobel Laureates. If you look at the lives of Nobel Laureates - can we draw some inferences? Can we learn some lessons, so that we can become better researchers. Then the traits of a creative engineer or researcher. And then, summary and we will see what are the ways to improve creativity. At the end of the day, there is no point in saying all these people were great, all these people were great okay; they are great; from their lives, can we learn some lessons? Can we also improve? okay

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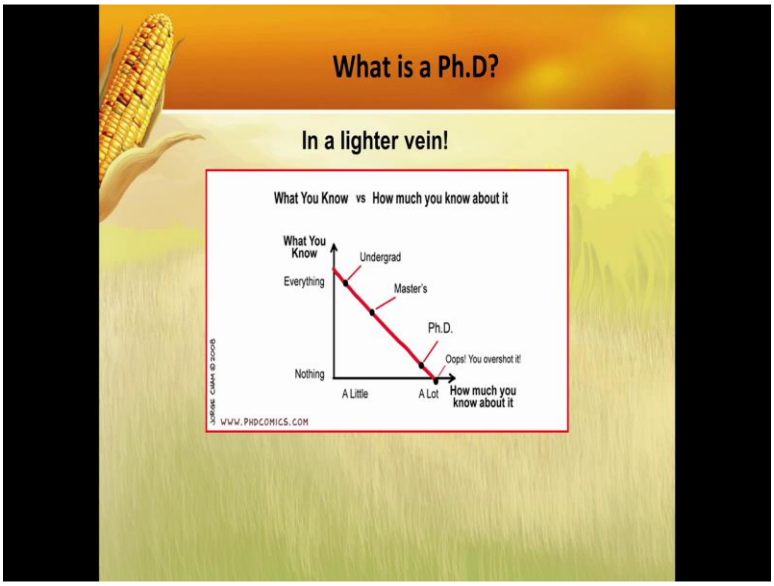

What is a Ph.D.? In a lighter vein… So, the y-axis, the ordinate, is what you know and the abscissa or x-axis how much you know about it okay. So, if you are an undergraduate student, you almost you get to know something about everything, but you get to know little about everything okay. And when you come to Masters level, you get to know something about… you get to know reasonably enough about many things okay, and slowly, your confidence goes down. You are having a doubt whether you know anything deep or not - that is the situation of Masters. When it comes to Ph.D., you know you know a lot; you know a lot about a very narrow area of research. When you become a fully professional researcher, then you know completely about nothing. So, jocularly, often refer to it as the exponential law or the inverse law. If you think you know everything you will get a B. Tech; if you begin to doubt that you know anything at all, you will get a Masters; but if you are convinced that you don't know anything, but you are also convinced that others also don't know anything, then you get a Ph.D okay. The last step will be if you are convinced that you know everything, if you are convinced that you don't know anything, if you are convinced that others also don't know anything, but you are also convinced that in your whole life time nobody can actually find out that you don't know anything, then you become a Prof. I know I am on air, doesn't matter alright.

So, this is the story. We try to know completely about such a small this thing, that it's almost like nothing. You take a particular problem – solar energy and like something parabolic solar collector - this thing you want to concentrate, concentrate and concentrate okay. So, sometimes, you have a doubt - when you proceed so much, when you getting so much of depth, will you not forget other things and all that, but the whole approach is you get so much depth that your clarity about a particular thing, you keep doing a tapas on that for many years, you are getting so much depth into that, but through that depth, the darshan or vision comes, then your ability to expand to other things radically improves, which you will not get if you just stop with… if you are not doing research. So, through the depth, your ability to perceive, understand other things will improve. So, we gain width through the depth; this is about it. That's why, once you have your Ph.D., and once you have… once you have gone through this process, your ability to appreciate, even you can sit in a presentation on electrical engineering, suppose all of you are in mechanical engineering, you can sit in presentation on electrical, metallurgy materials, whatever, then, quickly, you will be able to… you will be able to grasp what somebody is trying to say okay.

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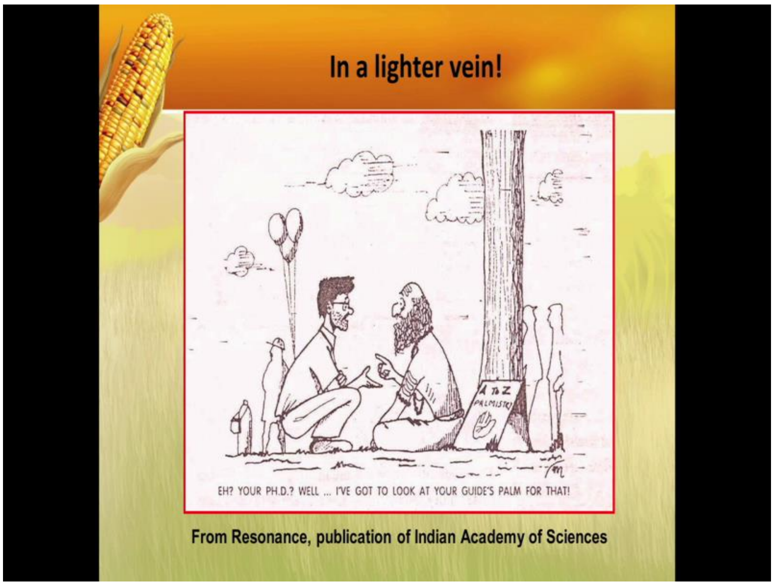

In a lighter vein okay, somebody has taken lot of years, his Ph.D. is not over after 7 or 8 years; he is growing a beard okay. He is going to an astrologer and palmist; he is saying to please look at my hand, please tell me, when I will get my Ph.D.? That fellow says there is no point in seeing your hand; please bring your guide; I want to see his hand. So, these are all in lighter vein.

Now, this is also, this is also super creativity. Teacher asks Peter to expand a plus b to the power of n; he keeps on expanding like this.

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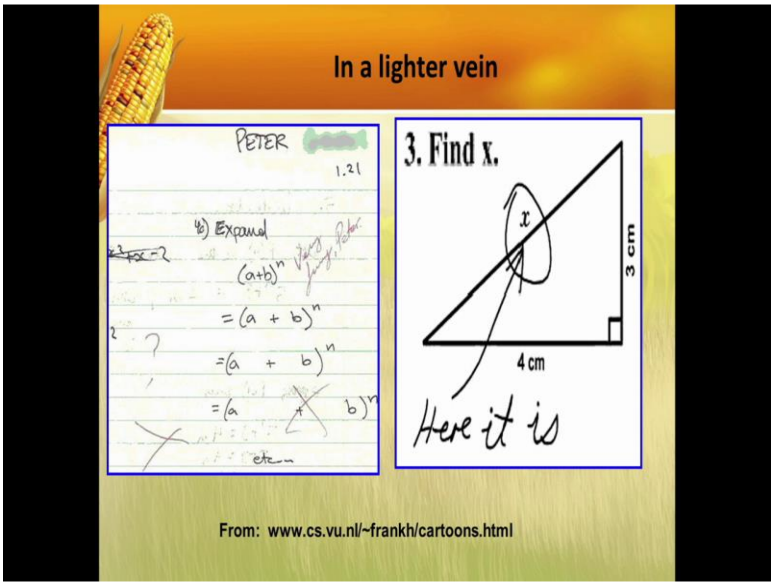

Are you getting the point? a plus b, a plus b, he is expanding that okay. This is also an instance in a trigonometry problem, where this is 3 centimeters, this is 4 centimeters. Find x. x is root of 9 plus 16, 25; he says here it is. So, you would have wondered. So, you can very well imagine what grade Peter would have got in the exam; this is also an instant of creativity; these are also instances of creativity, but we are not looking at this; we are looking at serious creativity okay.

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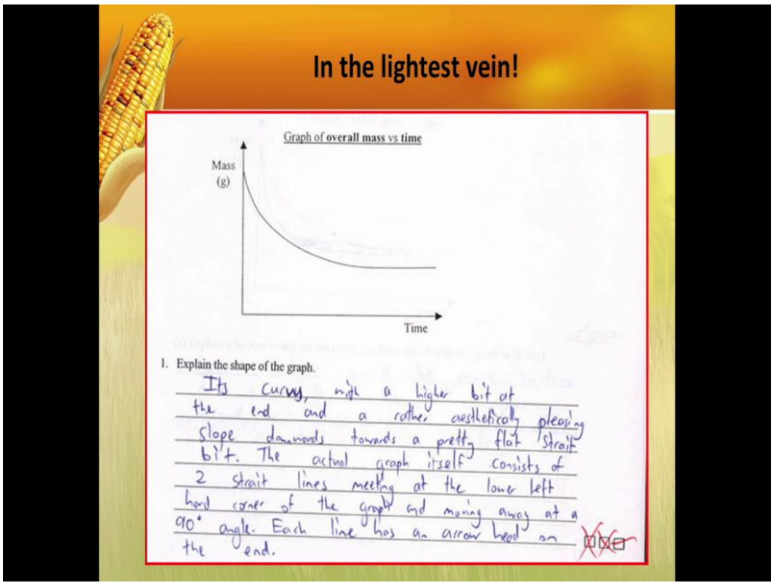

So, this is familiar to you. So, this a variation of mass with time. It is exponentially decaying okay. This boy does not know anything about it okay. Well many times people do that know; then he starts explaining – it curves with a higher bit at the end and a rather aesthetically pleasing slope towards a pretty flat straight bit. The actual graph itself consists of two straight lines meeting at the lower left and all that. That means he does not know anything about this curve. This is basically a, y equal to a into e to the power of minus b x kind of curve okay, alright. So, it's an exponentially decaying curve, which have cooling of a first order system okay.

If there is a hot object placed in cold surroundings, we will look at heat transfer. Initially, the temperature difference between the body and the surroundings will be very high; therefore, it will cool very fast; then, the driving temperature difference comes down; therefore, slowly the cooling will reduce; asymptotically it will reach the…; asymptotically it will reach the ambient temperature. Learning is also like that. Learning will follow an inverse this thing okay. It will be opposite of this. Initially, there will be explosive learning which is applicable to Ph.D. also; initially, you learn a lot of things. After 6 years, 7 years, 8 years, the learning will become very flat. Then it is a time to go okay, because even if you spend many years it will get saturated okay. So, that will be the inverse; you can very well imagine how that is; that is also e to the power of something curve okay.

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Now, we are not talking about those instances of creativity where somebody writes something here, somebody for fun does something, but we are looking at some serious creativity.

How do we become a fully professional researcher? See, if you are saying that… if you are saying that you are professional researcher - what is expected of you? We have something to say that our peers want to listen to; that is very, very important. We cannot keep on claiming that I am a great researcher; I am a great researcher. In an international conference, in an international meeting, that is ASME or IEEE, are you invited to give a key note lecture? Are hundred people ready to sit down and listen to you; will they give that half an hour or one hour to you? We should come to that level. There is no point in saying that I am great; I am great; it will not work. And that peer group must be truly international. It should not be peer group only in Chennai 36 or Chennai 20 or in Coimbatore or Nagapattinam or Visakhapatnam or whatever; that peer group must be truly international.

If there are 10 big experts, if there are 10 big experts in robotics or artificial intelligence, are you one of the 10, are you one of the 20 - that is what we want to aspire; that is what we want to get there. So, to do this, command of our subject is required for this. So, Rome was not built in a day; you cannot do, you cannot achieve this over night. So, soaking is required; it takes many years to get to this position okay.

For example, Nobel price is not given to upstarts. After you finish your Ph.D., you found something very interesting. After 5 years, they don't give Nobel prize. The first thing is you have to have a long life to win the Nobel price. Why? Whatever you figured out at the age of 25, 30 or 35, they will wait for 20 or 30 years. So that there is an opportunity for others to find out and prove or disprove whatever you said, whatever you said some 20-30 years back; therefore, whatever concept, whatever theory, whatever experimental results you have generated have they withstood the test of time okay, because time is a violent torrent okay. So, there are many things which get swept off by time. So, are your results having enough shelf life, that even after 20 years or 30 years, people are ready to accept it, and I mean, no other paper has come or no other paper has come which tries to say that whatever you have generated is erroneous, and they are getting results much different from what you got and so on. May be the accuracy may not be there, and after some years you may have better computers, you may have better experimental methodology, so that you can get some percentage improvement, but if somebody gets radically different results, and they contest your findings, then we will have to… then what happens is it opens up, that means the issue is not settled; when the issue is not settled yet, then it's still an open problem for further investigation okay. So, in order to do that you need to have a mastery of appropriate techniques in the field. You should have a mastery of all the techniques in your field.

For example, if it is thermal sciences, you should have a mastery of analytical techniques; you should have a mastery of numerical techniques; you should have a mastery of experimental techniques, because in your long life, you cannot stay as just an analytical person, because the problems which are available, which lend themselves to analytical investigation are slowly going down. In the fifties and sixties, you can do momentum integral method, this integral method, approximation perturbation method and all that, similarity transformation, eta is equal to y by two root alpha t all that kind of things - the kind of problems which can be solved using that approach they have come down. Therefore, analytical methods have some place, but still you cannot, I mean, just as they say you should not put all your eggs in one basket, then if one egg is spoilt, all the eggs will get spoilt; similarly, you cannot invest your whole career on analytical method because the area - analytical methods - may themselves vaporize or evaporate. So, your skill set must be in… your skill set must be all pervading, skill set must be diverse enough okay, so that the risk of obsolescence is not there okay.

So, if you proceed from analytical techniques, the next will be a..next will be numerical techniques. You should have mastery of numerical techniques, because we don't have the luxury, the time and the money, to have a research career, where all our investigation will be based only on experiments okay. At the same time, you cannot assume that your life - whole life - you will be working on some software like Ansys Fluent. After 5 years, 10 years some other different software will come or those problems themselves will not be very important; flow over a flat plate, flow over a flat plate; nobody worries about flow over a flat plate now okay. Therefore, you should have mastery of experimental techniques also. So, if you need to have this mastery, if you need to have this mastery of all these techniques it takes time okay. So, you have to spend time.

Then, also, once you are a fully… after you are a Ph.D., in your initial years after your Ph.D. and all that, you should settle down to what is called a line of investigation. What is a line of investigation I want to pursue in the next 5 to 10 years? 30 years may be a difficult time, because it may be a difficult proposition, because lot of things will change, but in the short term - short to medium term, the next 5 to 10 years - where is it that I am finding lot of gaps? Where is it I feel, there is that there is lot of excitement? With my skills in analytical, numerical, and experimental, my interest and my background, where is it I can make a contribution? This is a very important decision which you have to take alright.

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You should be able to communicate your ideas through papers and presentations very effectively; communication is very, very important. We should be able to give good poster presentations, when you are research scholar or a budding researcher or you should able to give good oral presentation in conferences, and then, you should slowly develop the knack of writing very well, the art of communicating your results, your findings, results. It’s not enough if you just got some great results, you should also be able to communicate okay. Same thing, you would have, you figure out that you have invented something which is highly creative; you may say it is creative creative, but other people have to accept it, isn’t it? Other people have to accept; after all, we live in a society and so on.

The Apple iPhone become such a massive hit. Apple iPhone is an icon of creativity because many people accept it, whatever they said, because they did something, they did many things, which are unthinkable - like a phone without any keypad, and then there is no stylus, the finger will be used as a stylus. So, when the market, at the time, was flooded with phones, which had big big keyboards, and the screen was very small okay, and there was always a stylus at the back. So, this ability to communicate your ideas is very, very important. So, this, for this maybe you will have to do some reading; you will have to do lot of reading which is outside your subject. You may do fiction, you may read fiction, you may read nonfiction, whatever; you have to do lot of reading to find out how different people communicate their ideas in different fields - how a newspaper correspondent communicates his ideas; how a science writer communicates his ideas; how a person like Chetan Bhagat communicates his ideas. So, you should get an idea, and after reading all this, you will get an idea how different people communicate in different ways, and pick and choose the best among all these, and then put your own spin, and come out with your own formula okay for writing and presenting.

And if you are in academic setting, you should be able to guide Ph.D. students sooner than later okay. So, your life doesn't stop with your Ph.D. If you are working in any… now even in CSIR labs and all that, you will have to guide students. So, you should be a fountain head of ideas; that means, you should be able to generate ideas throughout. So, the successful researcher is not somebody who is just very brilliant in Maths or very brilliant in Physics or whatever; the successful researcher is one who has the ability to keep on generating new ideas throughout his life time okay. So, it should come, for that for that soaking is required. And then, you should know what is going on in other fields, and then, you should have passion, you should have hard work, all these things will follow now okay. We look at all these in a little while.

If you are in the industry, you must be able to write and defend your proposals okay. You should be able to defend your proposals to your boss. So, you are a head of a R&D division, you have your finance and other marketing - all these people you will have to convince that please make this, I want to make a new engine. Then, they say, I can get the engine from some other company; why should I make a new engine? Then, you say that my USP is this; you say that I want a light weight, this thing, whatever be your USP. So, you should be able to defend your ideas.

Then, finally, the peer group must be truly international. Even in the case of industry he is the top, he is one of the top ten guys in emission control, he is one of the top ten guys in steering, he is one of the top ten guys in ABS, he is one of the top ten guys in networks; I mean some… So, we should try to get there. Only then, you can say that you are a fully professional researcher.

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What are the attributes of a good researcher? First you should have sound grasp of fundamentals, very, very important. You should have sound grasp of fundamentals. That is why you cannot do research immediately after clearing your plus two; you have to do your B. Tech; you have to do your M. Tech; then you do some courses. And so, you should have a lot of grounding.

Then you should have mastery of techniques in the field. For example, all of you are doing heat transfer; there are certain techniques which are in heat transfer - the integral method, similarity transformation method okay, how to solve partial differential equations, finite difference method okay, measurement of temperature, measurement of pressure, measurement of flowrate - also, these are all, I mean, these are all specific to heat transfer. Like that, if you are doing in electrical networks or communication engineering, there will be a set of things which you will have to master. So, you have to list out what are the things which are to be mastered, so that you can become a fully professional researcher in your field.

Then tenacity and perseverance. The experiment will not work. The program will not converge. The paper may get rejected. It may take a long time; the paper may be sitting with your guide for a long time. There may lots of frustrations, but in all these times, all these times you should show your resilience and see how optimally you will make use of your time; stay positive, keep learning, keep improving.

Then scholarship. You should you should have scholarship; that means, you should have a deep knowledge; you should have a deep knowledge about your subject; you should also have a good knowledge of what are the problems other people are working in; what are the kinds of problem in this field, where other researchers are working; you should know what are the problems your friends are working on - that is the scholarship. I know everything only about my problem; I don't care, I don't have interest in other things; this is not a good attitude. So, you should know, for example, the top ten, the top fifteen, the top ten or top twenty researchers in heat transfer or thermal sciences; what are the kinds of problem they working on now. What are the kinds of problem which are going on in your laboratory? Not in your group; your group, any way, you will know; you will go for coffee with them and you will know. What are the kinds of problem being investigated by other groups okay, other groups in other research institutes in our country, in our continent, in the world okay.

What are the kinds of papers which have been published in the latest journals – in IEEE or ASME or in Elsevier. What are the kinds of work? So, what are the kinds of work? What are the South Americans working on? What are the Americans working on? What are the North Americans working on? What are the Japanese working on? What are the Chinese working on? So, for that, you have to get scholarship; you have to read. Just I will work only on my problem; it will give you… I mean, it is like frog in a well okay; you should have a world view of the kind of… because lifelong you cannot be working in this problem. 3 to 5 years down the line, your problem will be well settled problem. Is it, okay, you have done enough, you got with your guide, you got the… you should not keep… you should not think that with that experimental setup, with that idea I will proceed for 10 or 20 years, then slowly you will get more and more rejection; then, there will not not be much fun and excitement in that. So, sooner than later you have to come out of your comfort zone and leave your Ph.D. problem and do something, but whatever techniques you have learned will stand you in good state in taking you forward.

Communication skills I have already told you okay; you can also look at YouTube lectures; you can look at NPTEL; you can look at open course, which are on MIT; you can look at other YouTube lectures. How different people communicate, present their idea; not necessarily in engineering; how somebody present his ideas in law, justice, psychology, physiology, whatever. So, you get a perspective okay.

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Creativity is often neglected. So, now, you are going to talk about creativity. What is creativity? A creative person does things that have never been done before okay. The first thing is it should not have been done before. There should not be a… there should not have been an iPhone before that Apple iPhone, then only it is highly creative. Important instances of creativity; discoveries of new knowledge in science and medicine - discovery of penicillin okay or acceleration due to gravity, universal law of gravitation okay, f equal to g m 1 m 2 by r square okay, it is directly proportional to the mass of the two objects, it is inversely proportional to the square of the distance between them and the constant is g okay.

So, invention of new technology - the fluidized bed combustion, the fluidized bed boiler - where you can burn anything; if you have a bed which has got a high specific heat made of sand, then you put whatever you want, you put biogas, this thing and all that, it will burn; this is a new technology. Composing beautiful music - whether it is by Mozart or A. R. Rehman, that is also creativity. Or take Indian penal code, take a particular section, some supreme court lawyer argues it in a way which nobody else has argued; that is also creativity. So, creativity can be in law, philosophy, history or interpreting history in a different way. All these are instances of creativity. We should not think that creativity means new mobile phone, new computer okay, internet and all these, they are all pervading and many instances of creativity which are constantly going on okay.

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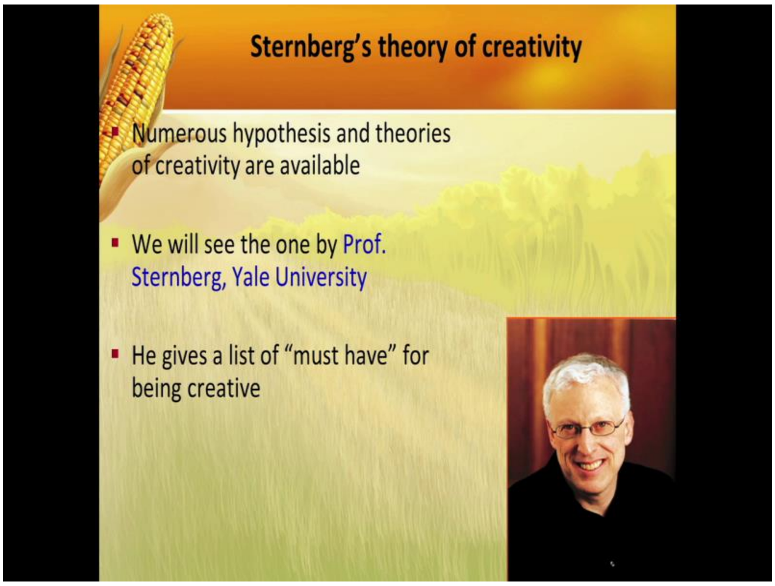

This Prof. Sternberg of Yale University, numerous hypothesis and theories of creativity are available. If you put creativity, you go to Google, it will give, it will return you millions of sites, articles, and all that. So, I picked up this because I find it very it gels with the theme of this lecture. So, this is Prof. Sternberg. He gives the list of what all qualities one should have or must have qualities in order that somebody is creative.

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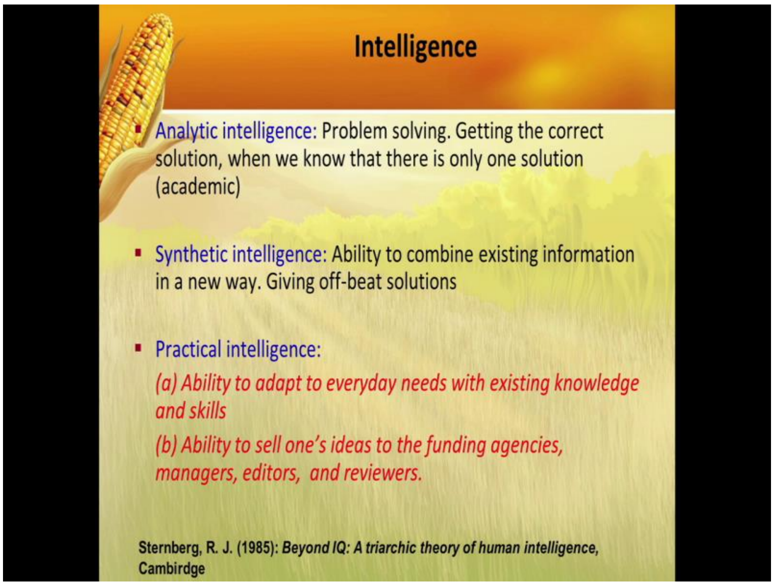

He classifies intelligence into three types, analytical intelligence, synthetic intelligence, and practical intelligence. This is from his book, 1985, Beyond IQ: A triarchic theory of human intelligence, published by Cambridge University Press; that is indicated at the foot note.

Analytical intelligence is what you learn in college; Mechanical Engineering divided into 4 years. Each year divided into 2 semesters; every semester you have 6 theory courses and 2 labs. Science of material, dynamics of machinery, heat transfer, fluid mechanics, turbo machinery - if you learn all this, if you get some… if you pass in all these courses, then you have learnt mechanical engineering; that is the assumption okay. And then how, how do you test it? There is a question paper; everybody is given the same question paper; everybody is given some time; nobody should look at each other's this thing; you should not look at books and this thing; and then you solve some problems. And the teacher knows the has the answer to the problem, and there is only one correct answer to that. So, it's a highly simulated environment. In this thing, you then put first class, distinction, some gold medal, silver medal, whatever. And then, you say, that he is a mechanical engineer.

So, this analytical intelligence is, basically, is we test your concepts, your fundamentals on problems for which solutions are already available; you are testing whether you can get the same solution. We now rarely we give problems in which… rarely we give problems which are open ended, where there can be more than one solution; then it becomes difficult, then somebody will say he got more marks, I got less, there are lots of problems okay; therefore, often this analytical intelligence, analytic intelligence, is theory class, lab class, exam, grades, and degree certificate okay.

Synthetic intelligence is the ability to combine whatever you have learned in a new way. The only place where you get, where you have a idea of the synthetic intelligence in your course, is basically in your B. Tech and M. Tech is your project work, where you try to apply what all you learnt, to solve something. Research is all about synthetic intelligence right; whatever you have learnt, you are making use. In a course-based program like B. Tech or M. Tech, so the only way where you learn is doing project or in a design project and so on. And also, in a synthetic intelligence, you can give off beat solutions and different people can get different solutions; that is often the case in life. In life, generally different people will take… Now, after this lecture is over, from 11:50 to let's say 12 'o' clock to 1 'o' clock, you can… somebody can go straight for lunch, somebody can go back to lab, somebody can do… life is a set of possibilities; everybody can choose his own okay; then what the cumulative effect of all these choices is what you become.

So, the synthetic intelligence, let's say, gives you the freedom that the solution finally is not fixed. There are different solutions; that's what normally happens in design. For example, in heat exchanger we always talk about two kinds of problems. There is a heat exchanger which is already available, you have what is called the analysis or rating problem, where you want to find out, you want analyze and find out how much of heat can be transferred with this heat exchanger okay; then everybody will get the same answer. But now I have 100 kilowatts of heat to be transferred, I decide the type of heat exchanger, but how many numbers of tubes, what is the length of the tubes, what is the diameter of the tube - that is a design problem, different people can get different solutions, is it okay.

Practical intelligence is the most difficult. Ability to adapt to everyday needs with existing knowledge and skills, and ability to sell your ideas to funding agencies, managers, editors, and reviewers, practical intelligence is never taught, it's also extremely difficult to teach; you have to acquire it over the years. So, practical intelligence is as important as analytical and synthetic intelligence. But if you see the triarchic theory of intelligence, out of the three, only one is excessively focused in all your education. So, the other two, you will have to pick it as you proceed. So, your success, eventually, will depend a lot on the other two also okay, and these are to be self learned.

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Knowledge. What about knowledge? Knowledge gives us the ability to recognize what is genuinely new. Why cannot you start research immediately after plus two? I have lot of brilliant ideas. Let me start research. The basic problem with that approach is, first, we should know what all have already been done in a particular field; otherwise, you will say the best way to transport is to have a circularly shaped object, with hub in between, and spokes, and then, you will come out with the design of a wheel which is of 500 or 500 years old or something; you should not reinvent the wheel okay.

So, only if you go to journals, only if you go to reference books, only if you go to text books, for example, in heat transfer you will know what has been done in the last 100 years; only after you know what has been done, there is possibility for you to do something new. How will you know, how will you get to know what has already been done? For this, knowledge is required. You have to go through the basic courses. Then, you have go through the advanced courses. Then, you will do the literature survey. Then you will get to know what is already done. So, some humility is required. You may have brilliant ideas; that brilliant ideas hundred people would have got, and then twenty people would have tried, and they might have even published, and it would have also been a failure. So, knowledge is very important because it gives you the ability to recognize what is new, you should know what is new okay; it also gives you the skills to design experiments, design new products okay.

How do you design your experiment? How do you measure a temperature of 500 degrees centigrade? You may have a lot of ideas, you remember how to measure temperature, when i went to the clinic, doctor put a mercury in glass thermometer in my mouth. So, you are brilliant; you got some brilliant ideas. Have you used this mercury in glass thermometer? I will use this mercury in glass thermometer to measure the temperature of liquid which is 500 degrees. Your brilliance will not let you know how to measure temperature. You should have knowledge; you should have platinum resistance thermometer or if it is a surface you will have infrared, therefore, you must know what other people have done. You should have knowledge; creativity is one, but knowledge is very important okay.

How do you design the experiment? How do you measure a flowrate? How do you measure pressure drop? If you will use special draft, you cannot use U tube nanometer. H rho g. What's the maximum h rho g? How much or you will climb a ladder to find out what is that h? Are you getting the point? So, knowledge is very important.

Then analyze experimental results. You are getting huge amount of data. Data logger gives you so much of data, how do you analyze these results? You should know there is something called heat transfer coefficient, there is something called nusult number, there is something called coefficient of performance, there is something called efficiency; so, that comes from knowledge. And then, you require knowledge to do scientific computing. I want to solve the equation d square 5 by d plus d square 5 by d square equal to zero. First, you should know that it is a partial differential equation, it is linear, it is elliptic, it reverse boundary conditions on four sides. Three kinds of boundary conditions are available. Then, there are various ways of solving: you can use a Fourier series or you can use finite difference or you can use finite volume or you can use finite element. You should know the formulation. All these dosen't come from your brilliance; with brilliance, only to certain extent you can go; it has to be supplemented by all this okay.