Design, Technology and Innovation
Prof. Amaresh Chakrabarti
IDC School of Design
Indian Institute Science Bangalore

Lecture-20
Research to Innovation Part 1

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Well thank you, Prof. Chakravarti for calling me here. That is me, so I started my journey as a mechanical engineer at *Shibpur*, and then did a master's in Mechanical Systems Design at IISc Bangalore. Then I had a small stint at Hindustan Motors as a design engineer, and then I moved out to do my PhD. I did it in Design Synthesis at a University of Cambridge with Nehru Fellowship. And there I actually studied and also developed a program, an early AI program.

Artificial intelligence has gone through a resurgence. You know, in the 1960s to 80s it was a heyday of AI and then now, again we are seeing a resurgence of AI, but a very different avatar. And at that time (it was) highly symbolic manipulation oriented rather than statistics oriented. And so I wrote a program that can actually invent new ideas. And then I stayed in Cambridge for about 10 years, leading its Design Synthesis group and then I came back here and joined IISc, where I now teach since 2001.

Let us take a few examples which I hope will excite you about the kind of things that the students or ex-students do.

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The first one is a chapel, yeah, a flip-flop.

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This is Govind Sharma here and Anup Chander;

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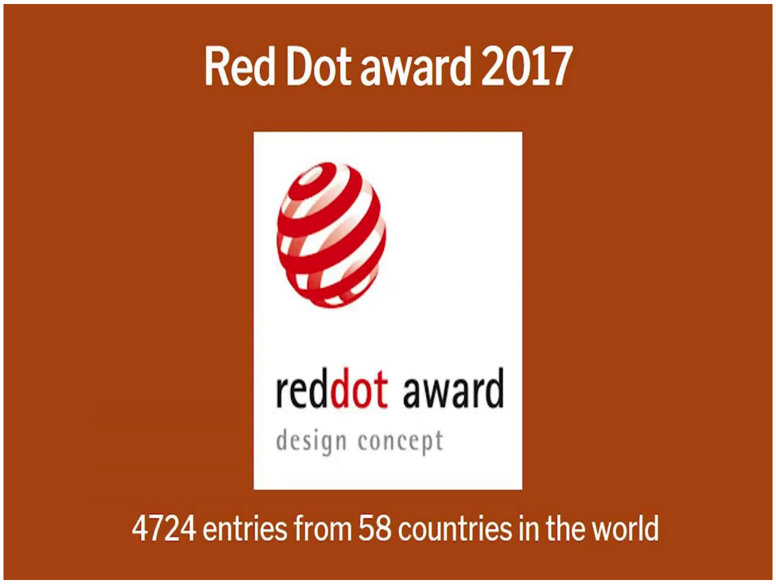

And in 2017 they received the RedDot award which is sort of the Oscar of design awards for redesigning chappals such that it does splash water.

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You know a major problem with chappals is that if you are in muddy water, you will start getting a nice spray on your back.

This is a slightly different emphasis. It is an invention.

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And this is Mona Sharma, another ex student who is working in a Bangalore based startup. She is the design head.

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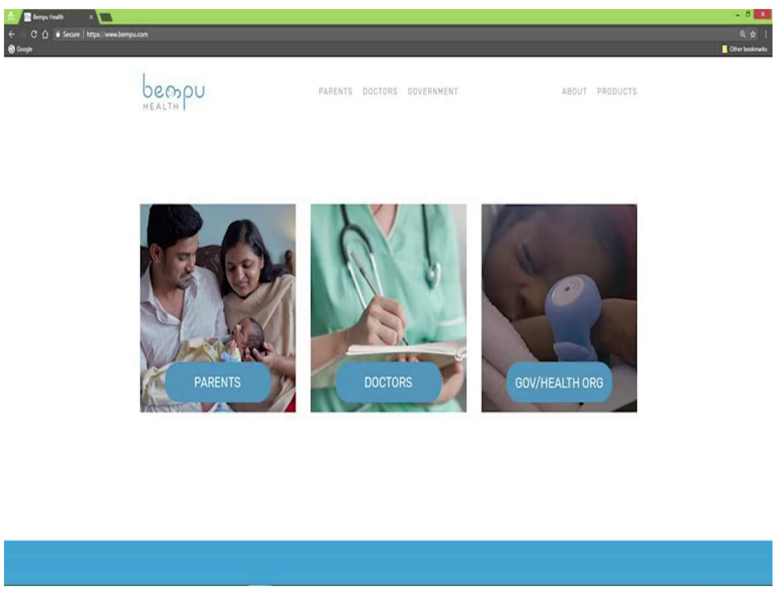

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And her startup, Bempu they, created a wristlet that goes into the hands of babies and just senses temperature and whenever the temperature goes beyond a certain number it will send an alert to the caregiver. Whether it is the mom or whoever else is in charge. And by doing that they actually saved the lives of 25,000 newborns in 15 countries. Why? Because hypothermia, a sudden drop in temperature of babies is a major cause of deaths.

You have to warm them up but how do you know that temperature has gone down? When has temperature gone down?

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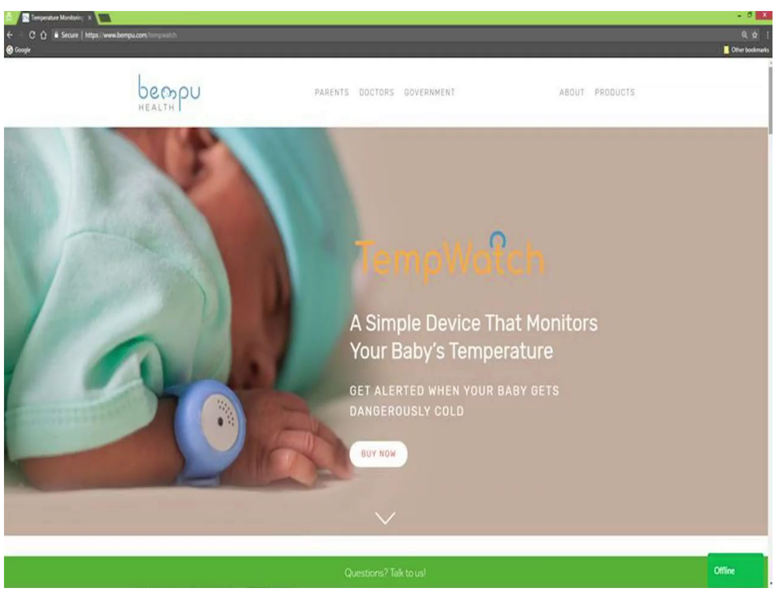

So, it is a very simple invention but very, very effective invention.

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The third one, outstanding industrial design and that is TVS Apache.

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So, this is Arun Kumar Frances, another ex-student who has done the form design for the TVS Apache Akula 310. As you know TVS actually makes BMW bikes in India and this is their first venture into creating a racing bike in the country and of course it had to have a form that matches that. You know of course you can come up with good ideas, nice inventions, brilliant solutions but if it does not go to society then it does not make the change, right?

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So, Sickle Innovations is a startup that was created about 5 years ago by 2 M.Des students: Nikhil Meshram and Nitin Gupta to basically pick cotton from the field. That is a difficult task, not many people are interested in doing and it does not give them enough money to stay in that business and there is a small window during the year in which you pick cotton, you do not pick cotton every day, and that makes it even more challenging to keep some of these people interested in that profession.

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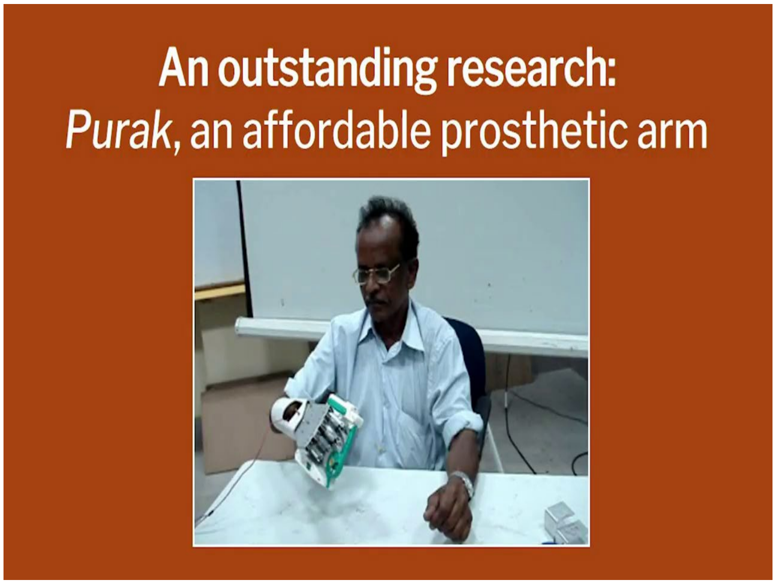

The last example is where the importance of research shows very clearly, and that is Purak. Purak is a prosthetic arm. This is a colleague of mine. His name is Eknathatn and he was one of the finest welders before he lost his forearm and as a result he is unable to do that quality of welding.

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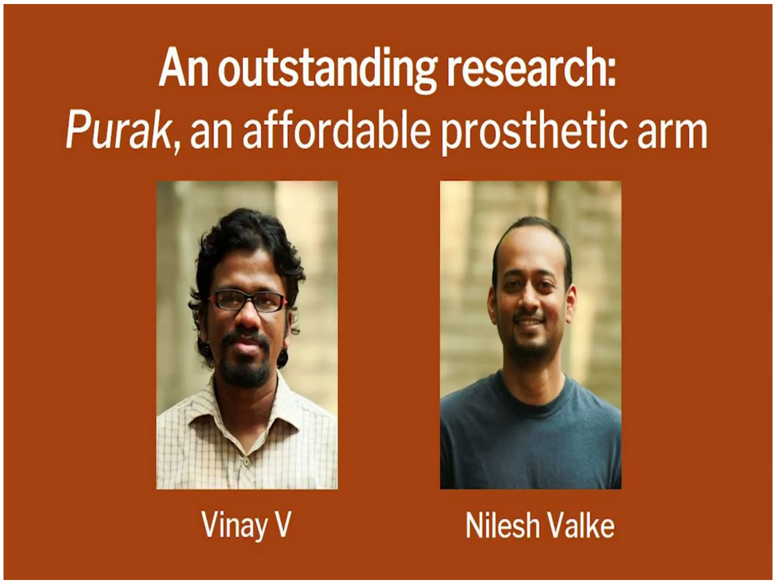

And these two students, Vinay and Nilesh, wanted to bring him back to the workforce so they did a master's project on creating an advanced affordable prosthetic arm.

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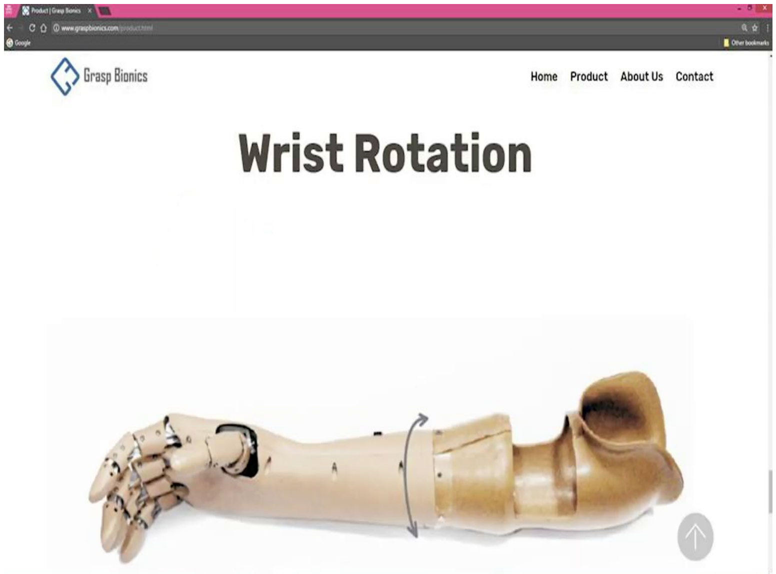

So a prosthetic arm that becomes far more affordable than anything that is available. And at the same time in order to make something so incredibly affordable, you have to really think out of the box and look at technologies beyond just changing the current a little bit. So, for something to be seriously affordable, it has to be also seriously advanced.

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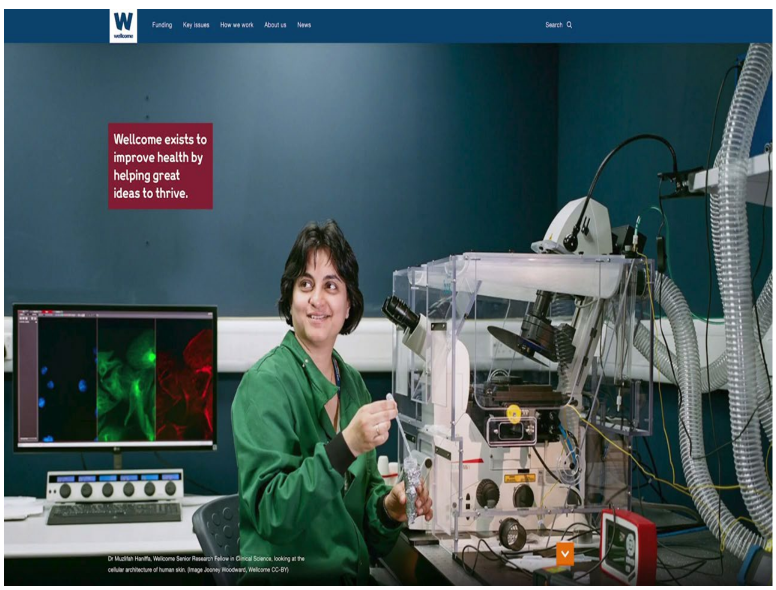

So, they got interested there then by Wellcome Trust, which is a global funding body based in the UK. They gave them another 10 crores to develop this further, with a collaboration with University of Oxford.

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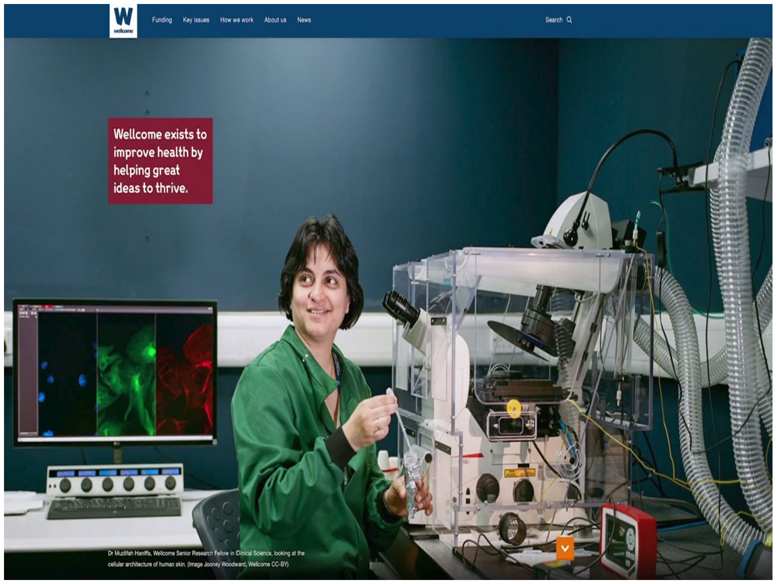

And now they have created a company called Grasp Bionics. This is an example of good research. The way in which you pick something depends on the ‘something’.

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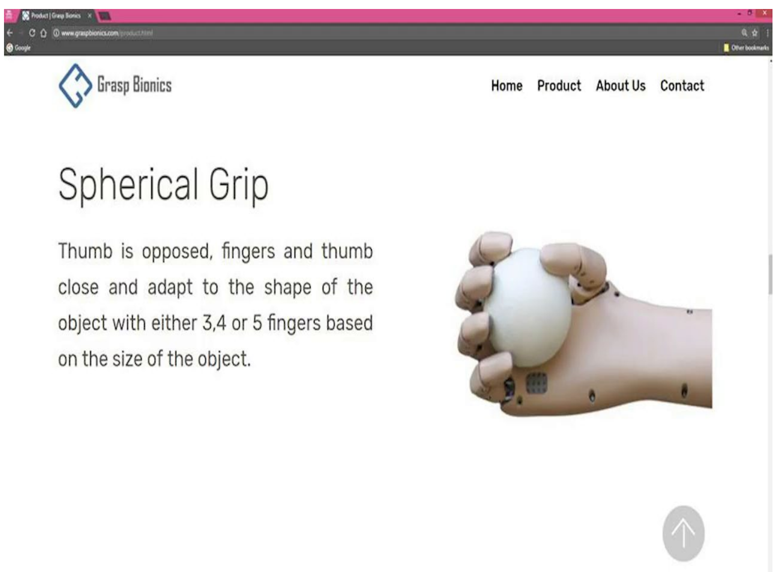

Now imagine a prosthetic arm that has to do that. Giving a flower is very difficult. It's a very soft object.

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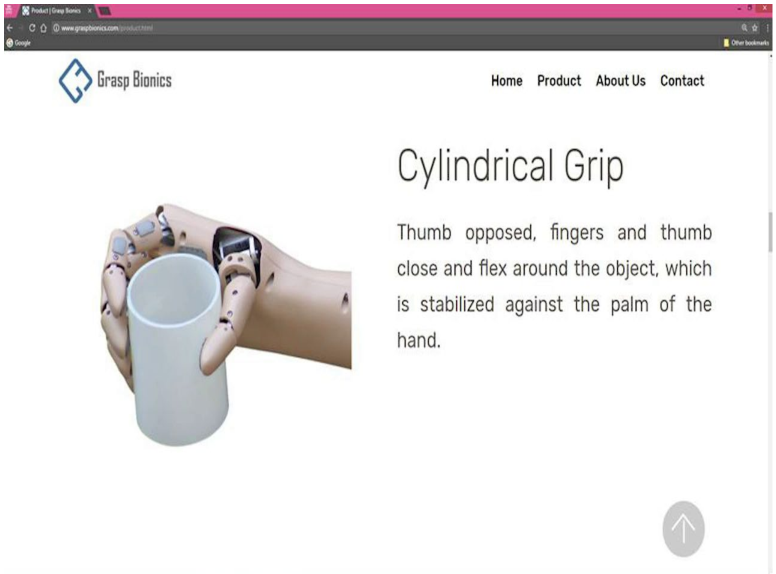

Even more difficult is a very flimsy plastic glass with water and holding it such that the glass does not deform, right? How are you doing it?

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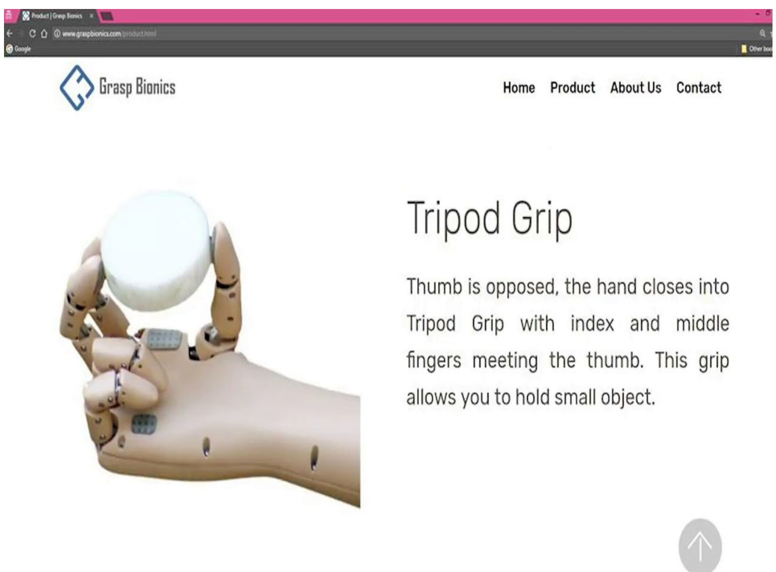

We are doing it with multiple sensors and actuators, right? So what did people do? People said, ‘All right, let us throw as many sensors and actuators and then put some controls around them so that an arbitrarily shaped object with the arbitrary flexibility can be held by multiple fingers’. What happens as a result? You have a very heavy, bulky, complex device that people find very difficult to use. So, it is very difficult to train and also it is very expensive because there are so many actuators and so many sensors. And therefore, you know, these things cost somewhere between 5 and 50 lakhs. So, these students said, ‘Can we do it at 20,000’, and they did that. And how they did that is because of good research.

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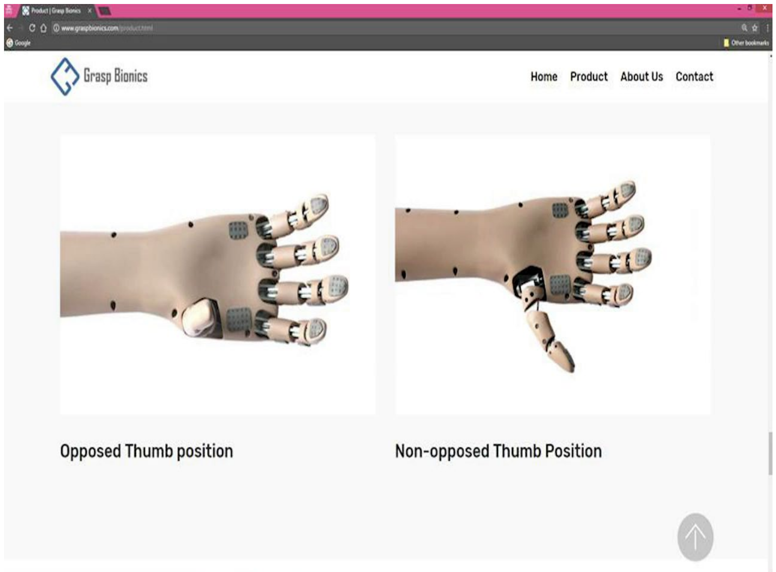

They were able to come up with what is called Under Actuation, where you use a single actuator to operate 5 different fingers in a coordinated manner, so that it wraps around and arbitrarily shaped object and something called bio mechanical sensing whereby the movement in the muscle can be sensed as a signal for it to operate.

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Now what is it that enables somebody to do all of that?

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So, to do that we need to understand that there is this thing called Business which is interested in money. It does not matter whether you are doing social innovation, you know, or not, you have to fill your stomach, right? Somebody has to pay you, so there has to be money. So they are doing it for money. They call it Profit, the difference between the price at which they sell and the price at which they did everything else for that object, so that they can sell.

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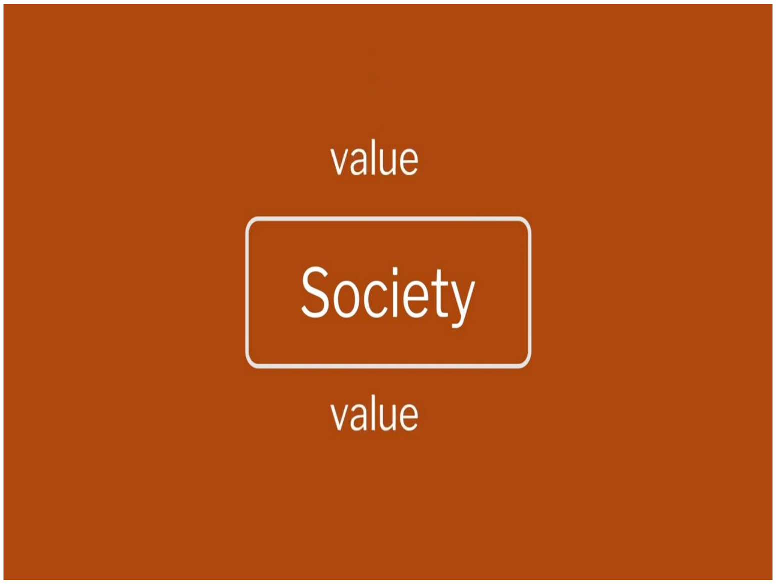

There is this thing called Society, and what the Society does is that it says, ‘I want Value’. What is Value? The Value is not just based on price, right? So, one simple way of looking at it is: What is it that you want? and, What is the price that you pay for it? Right?

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If you take this thing: How does it produce that Value? It produces that Value by either integrating technology or by creating technology. So, if we agree with that, then value is performance by price and profit is price minus cost. What is it that is in control for us as its designers?

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We can actually tweak two things. One is Performance, okay? And the other is Cost. It can be the cost of the environment, it can be the lifecycle cost of a product and so on. Now for this venture to be successful both Business and Society have to agree that we like it. Ok? The Business likes the Profit and the Society likes the Value. If they don't, it's not going to work. It has to be a win-win situation. So, we need to understand the needs of the user, right? And the aspirations of the user and immerse in the user context.

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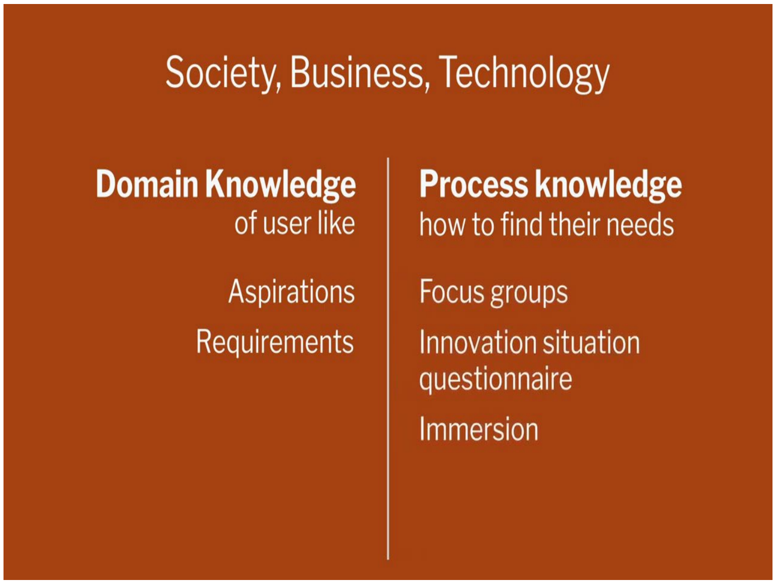

And to do that we need to have two things which I broadly call Domain Knowledge and Process Knowledge.

Domain knowledge means the knowledge of 'What is', Ok? What are the users like? What are their aspirations? And Process Knowledge means, 'How to find that', you know. How to process? How to create this knowledge? Is process knowledge.

Here is the second example. Now there is this disorder called muscular dystrophy. So, there is a protein called dystrophin in our body that is essentially a messenger between the signals that come from the brain and the muscles. So if there is less distortion, there are less, weaker signals that would go to the muscles. The muscles will not operate often and as a result over a period of time the muscles will not remain strong. And this is something that is dominant in younger children, men and it is recessive in women, so women will survive for a long period of time but at a very low quality of life.

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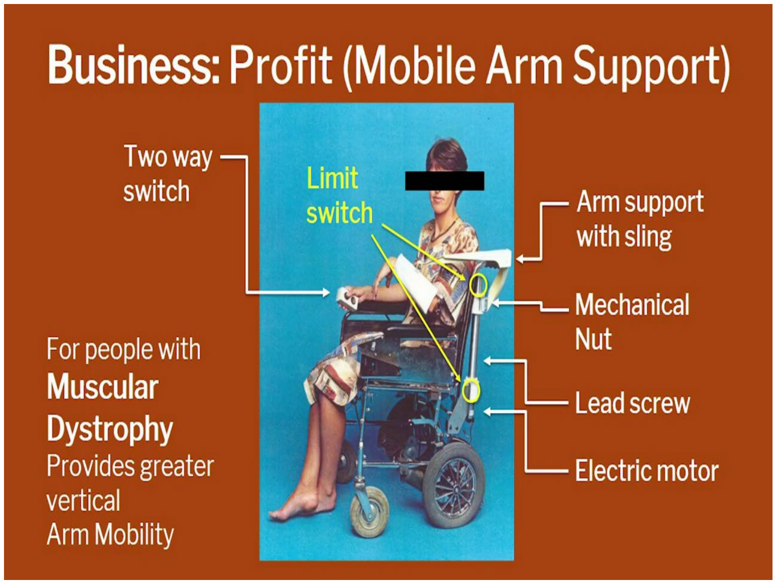

So, one of the things that we did in Cambridge, that I was part of, was to develop a simple device which we called Mobile Arm Support. Now what is Mobile Arm Support? These people would find it very difficult to move their arm up and down, because that requires much more force than going sideways. So, we developed basically a glorified lead screw that you can rotate with a motor here. So, if you have a screw that you can rotate and if there is a nut, the nut will go up and down, if you do not allow it to rotate, and that is all that it had.

So that is the nut, and then here there is an arm. An arm with the sling with enough degree of freedom that the arm can use inertia to move about. And with just that simplified device, and you have just a 2 way switch going up/going down. And 2 limit switches over there and over there, to make sure that the nut does not go out of the lead screw. That is all that it has, as a result it is very inexpensive. So we went to British Muscular Dystrophy Society and they said, ‘Brilliant product’. So we had to do field trials, we’ll talk about piloting later. When we went for field trials, we went, I went with a colleague of mine at the outskirts of London. And there was a lady, recessive lady, so she survived, she was 37, 38, she agreed to be a guinea pig for us. So, she had her wheelchair. So we connected the device there and we said, ‘What would you like to do?' She said, ‘Well, I want to type on my computer’, so we said, ‘Fine, let us go’. And she sat there and there was this keyboard, right? The keyboard was about one and half feet (above the ground). And she put her hand like that and she slid her arm like that. It took less than a second for her fingers to go from one side of the keyboard to the other. She started crying. So we all got very, very worried because normally people would not show their emotions, right? In front of strangers. Anyway she collected herself and we said, 'Is there anything wrong?' She said, 'No no, it is the first time in my life that I saw that I could take my finger from one side of the keyboard to the other in less than 5 minutes'.

So this is the kind of change that you can bring to people's lives, Ok? And only if there is Profit. So what happened was that for 10 years, we could not find a person or a company that was ready to take this as a product and turn that into a business. Why did they not do that?
Because: who are the customers? They are the customers, they are all wheelchair-bound, right? They do not really earn any money. So, the amount of money available for them to do stuff is limited.

This product is what is called a High-Risk product. In case one product fails and somebody gets injured, they will sue the company. And the company will go bust unless the company has taken large insurance to ensure that in such cases somebody will pay for that. And in order to take the large insurance, where are they going to get the money from? They are going to get the money from the same people from whom they are going to sell the product, which means the product price is going to go up.

If the product price goes up and the ability for people to pay is low, this product is not going to sell. Therefore, it is not a business proposition. Therefore, for money many years nothing happened until in 2008 I received a message from a colleague of mine, one of the professor, Ken Wallace. He said, 'Finally your product is out in the market'. What happened was the Government agreed to pay for the difference, okay? And suddenly it became profitable because the company gets the profit and somebody pays for it, partly paid for the person and partly paid for the government. And then it becomes a value proposition again.

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So, once again you need to have Domain Knowledge: What is the cost of the material? What is the cost of labour? What is the cost of manufacturing? And so on. But you also need to have the Process Knowledge of modeling costs.

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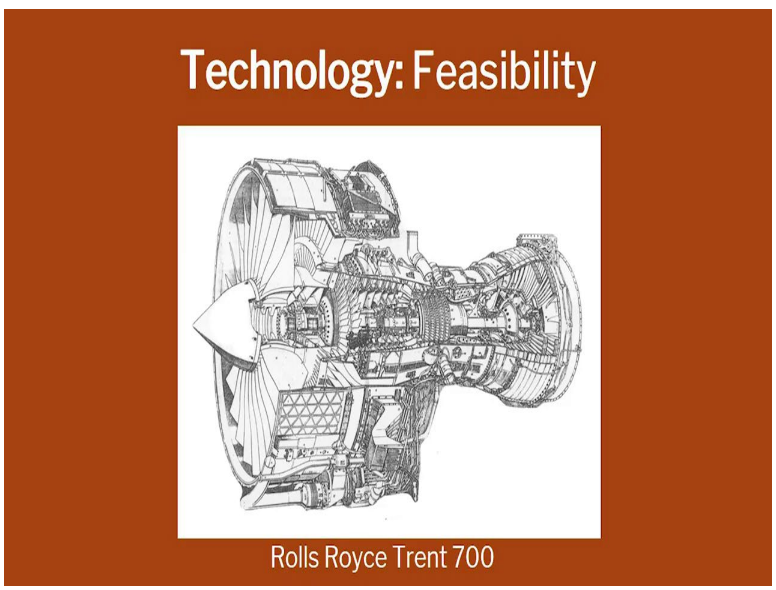

Last but not the least of course is technology. This piece of hardware was so liked by the customers that Rolls-Royce had to stop producing it. Now why do you stop producing something that everybody likes? Because if you do not do that they will not buy your new products.

There is a particular part of it that I would like to talk about, this little piece here, which is called Nose Cone. So, you want to have the Nose Cone so the airflow around that becomes nicely distributed and you do not lose energy much. But it also has side effects.

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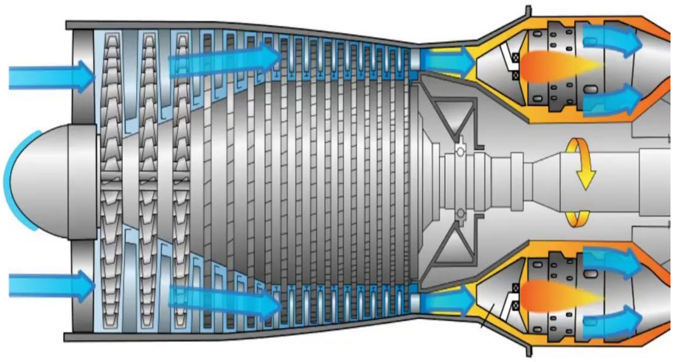

Imagine an aircraft is flying at 1000 kilometres an hour, 30000 feet. The temperature is such that where snow will start forming, and because of the compaction that will happen, because of the air flow, the snow will turn into ice, very brittle, it will break. It will become little bullets that you are shooting at these very expensive, high temperatures. The blades are very tiny here, right? And very big here, because it is getting pressurized. When the air is getting pressurized it requires less space, right? So, those are very expensive blades. There are single crystal blades that operate at a temperature higher than the melting point of the material. Now think about how they do that, there are very interesting technologies to do it.

How do you ensure that they are not shot at with bullets? Right? So this is a problem that engineers and designers have been working for a long time. What did they do?

The first thing that comes to your mind is heat the cone, so that there is no formation of ice. Bad news because if you remember Value is Performance by Price. What is the price of that, you know, heating against -50 degree Celsius?

And then somebody said, ‘Why don't we think of this as two pieces where the front piece can be attached with a wiggle motor’. It rotates and then rotates in the opposite direction and it stops.

Now if you have a wiggle motor that you can program at a frequency at which it wiggles such that it is faster than the time that it takes for snow to become ice, snow will never become ice. And therefore, snow will simply break and it will fly into the aircraft engine and nothing will happen because it hardly has any inertia, right? It is fluffy. So it is lower cost, right? So remember Performance by Price. Now we are getting the same performance but you have less price.

Why cannot we make these out of flexible materials. So, if I can keep the front part slightly flexible then what will happen is that the object will vibrate, because there is enough energy around. If it vibrates a little bit that will be enough for preventing formation of cone. And now you have increased the value very substantially, right? You have shifted the problem from the energy domain to material domain, right? Pretty much everything can be done either using material or using energy. The biological systems all push the solutions from the energy domain into the material domain because energy is so expensive for biological systems.

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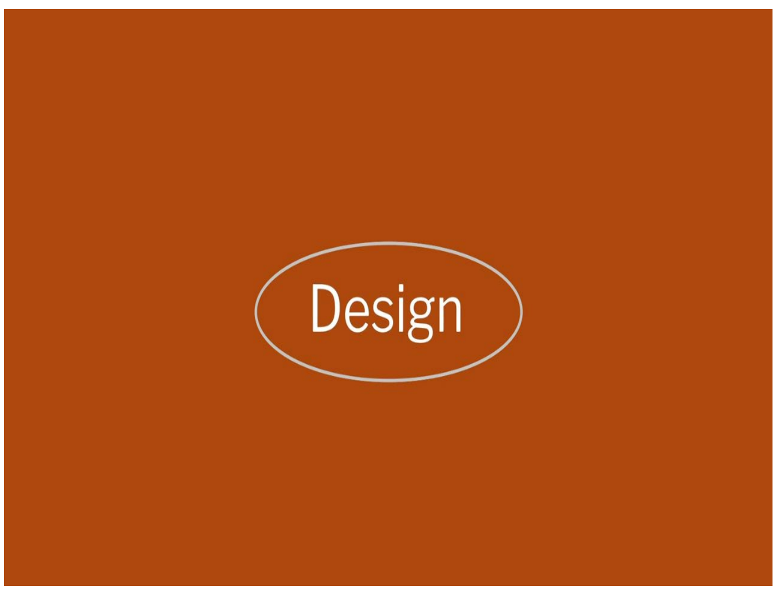

So, the knowledge of Society: What people value, and so on. And knowledge of Business: What would be sellable, what would stakeholders like. And knowledge of technology: What is possible, must come together and design is the great integrator.

See it is interesting that human beings become more creative when they have less resources. So, deprivation is not a bad thing.

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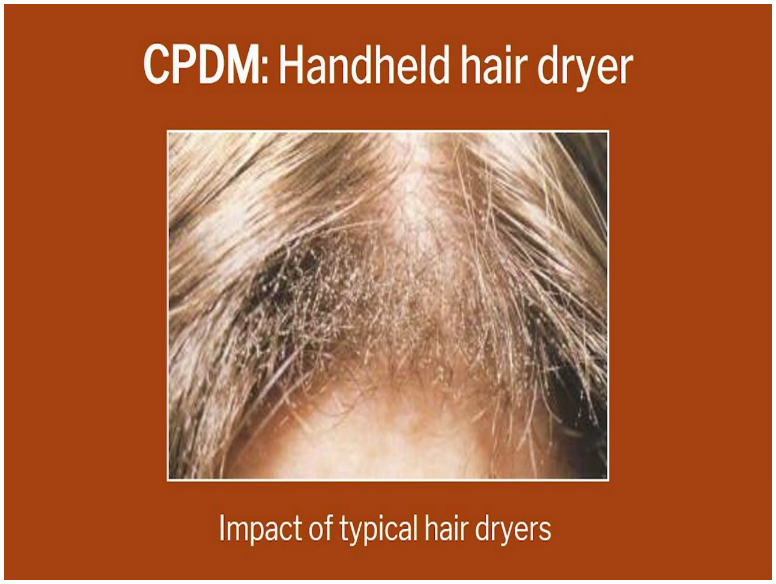

So, here is an example from Computed Aided Product Design, CAPD.

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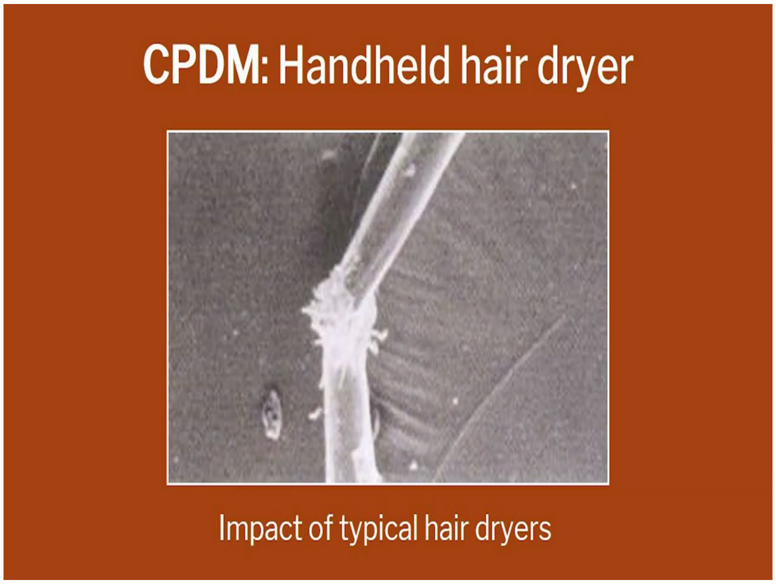

So, in this case the deprivation was that you have a hand held hair dryer that you have to design except that you cannot use heating elements, right?

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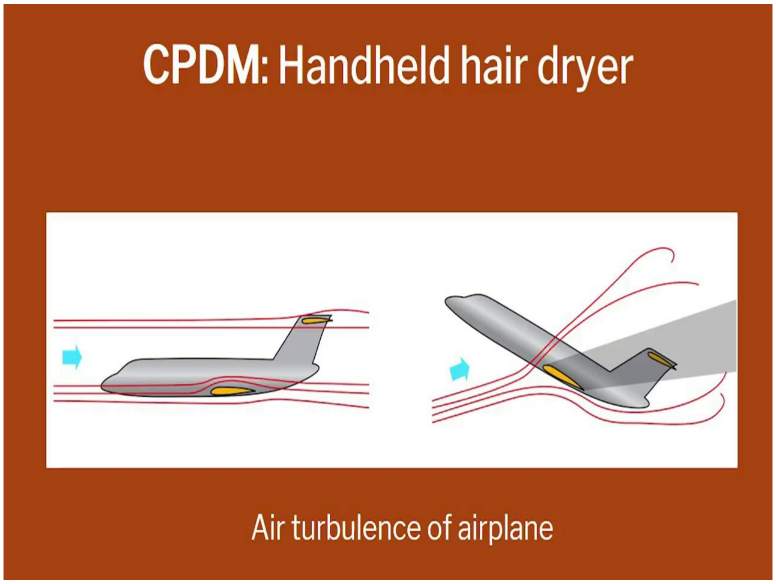

So, what Himanshu (the student) did was he looked at something that aerospace engineers hate and that is turbulence. When you have this wing for example, you want the air to flow nice and smooth on it. That way you reduce or minimise the energy dissipation across the layers and when energy is less dissipated the system is more stable. When there is swirl in the air, there is a greater chance of mixing and as a result of losing energy.

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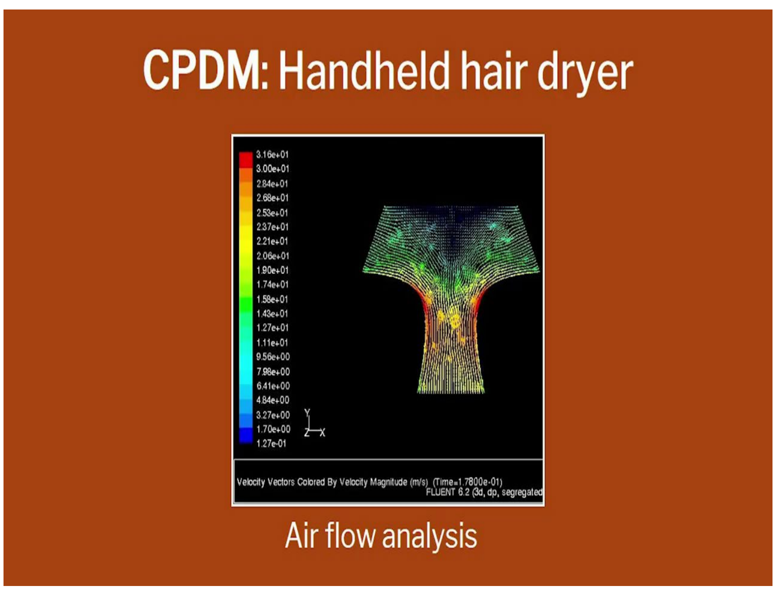

So, basically what they created is a glorified vortex generator. And how did they do that? By bringing in technology.

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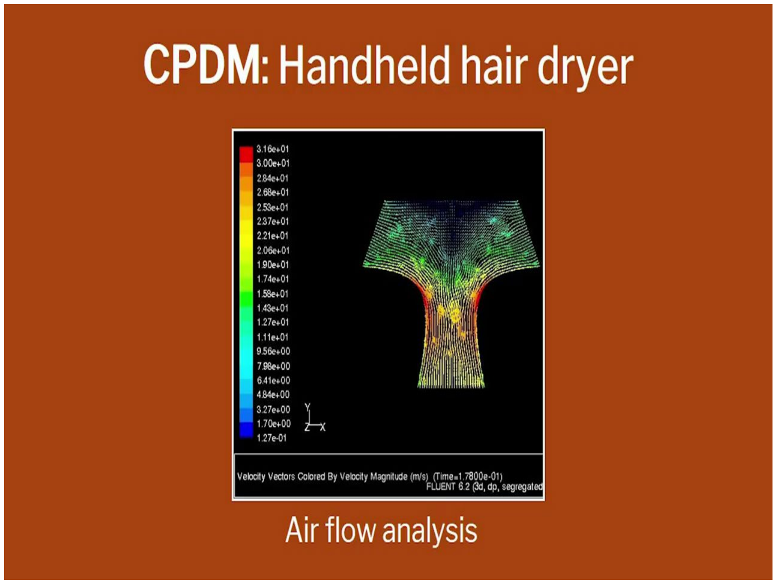

Can you use two fans for example to create two opposing flows of air which will then mix and create these twists. You know, you can use methods and tools to look at the flow and see how it is going to come in and so on. But also you have to say, ‘Ok, what is the message? How is the person going to hold it?

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So, this was something where you can hold it in the middle and you get two spouts of air coming out in order to dry the hair. And of course it should look good and it should be usable. So, usability, aesthetics and functionality must come together.

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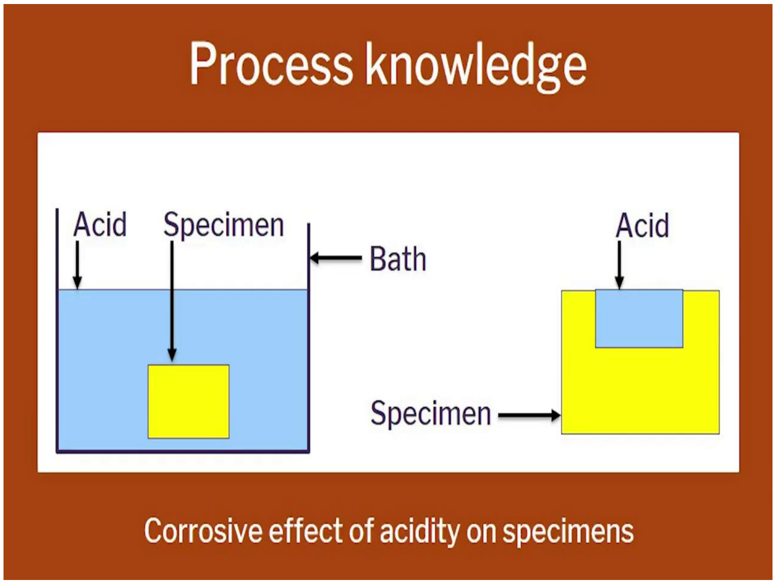

So, this is a sketch for another sensor. In this case it is sensing corrosivity. How corrosive these blue acid is for this yellow specimen.

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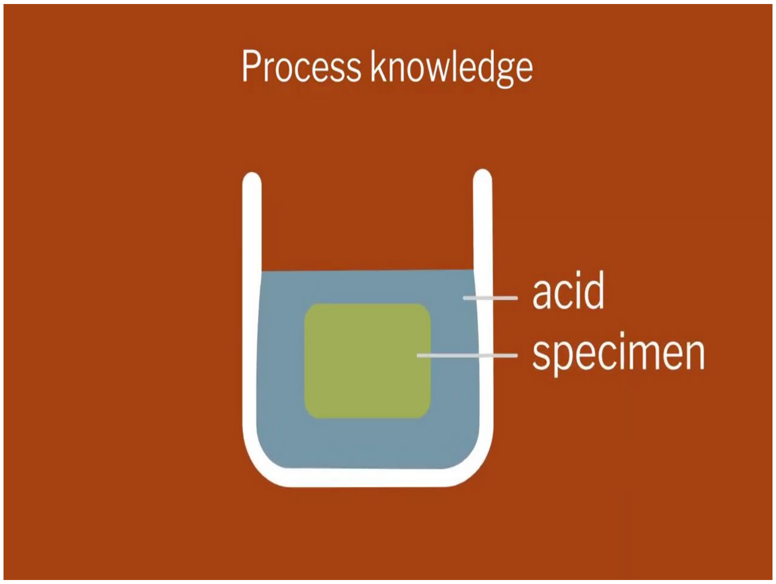

So, what you do is you have a bath, acid bath, and you put the acid there. You take the specimen, you plunge that in. You leave it for a while, for a specified period of time. You take it out and see the difference in size between the original specimen and currents specimen. And it is the difference in size which is an indicator for how corrosive the acid is for that particular material of the specimen.

But the problem is that acid is very democratic and it does not discriminate between the lining of the bath and the specimen. So as a result this very expensive lining also gets corroded away and that leads to a very expensive process of re-lining or throwing it away and creating a new one, so this is a problem.

And there are many solutions that people have suggested in order to overcome that. One of which is of course changing the material of the lining of the bath, right?

But then can we have simpler solutions. This has driven people and this is my personal favorite.

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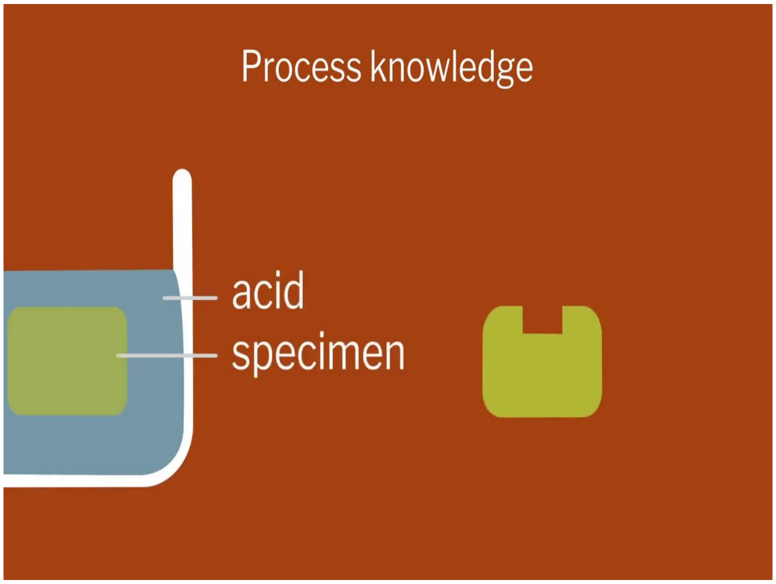

Turn this specimen into a bath, right? What you do is you make a little hole on the top, a blind one and then you put drops of acid there, leave it for a while and see the difference in size of the hole after a certain amount of time has passed.

So, the question now is that you do not need any further domain knowledge then you already had here in order to create this idea. So, therefore it requires specialist knowledge that something that we can inculcate and it is not domain knowledge.

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So, what do we do to train our students in a structured design process. When you are designing something that is incredibly complex. One example would have been the Trent 700 engine that I showed you, which has something of a million parts, and typically it would require about 5,000 engineers to be, or people to be collaborating with each other, you need to have a process that can symphonise that activity.

Of course if you are working on a technically intensive product then you need to have a technical orientation. You need to have an understanding of the user. We (must) remember, Society was one block, so emotion to the user environment. Understanding them as they understand their problem is very important. Realizability is very important. You know, we are going to talk about piloting and production and so on later on. You know, being able to make and see whether it works, where it works, where it does not and how to change it, is very important.

Therefore learning by doing becomes very important and as I said to you earlier, research can play a significant role in all of that. You need to have the domain knowledge and the process knowledge with which to do it. So here is one process that I want to run through with you and the process has only 4 steps. We start with class clarification. So, that is sort of doing the research.

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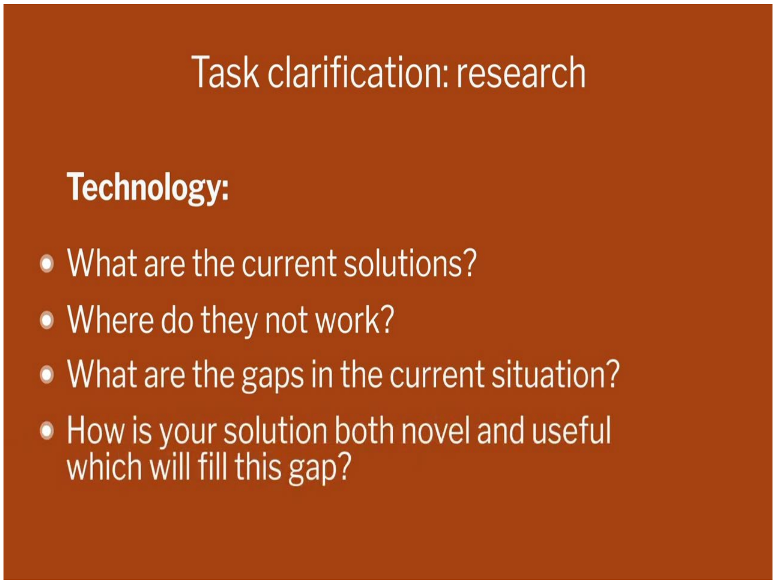

So in the Society you need to ask: Who are your stakeholders, who is going to make it, who is going to consume it, who is going to distribute, market, maintain and, you know, retire. Who are your competitors, what pain would be relieved and what gain would be received if you created a solution.

Technology: what are the current solutions that are there right now, where do they not work, what are the gaps in the current situation that you would have that are both novel, new and also useful.

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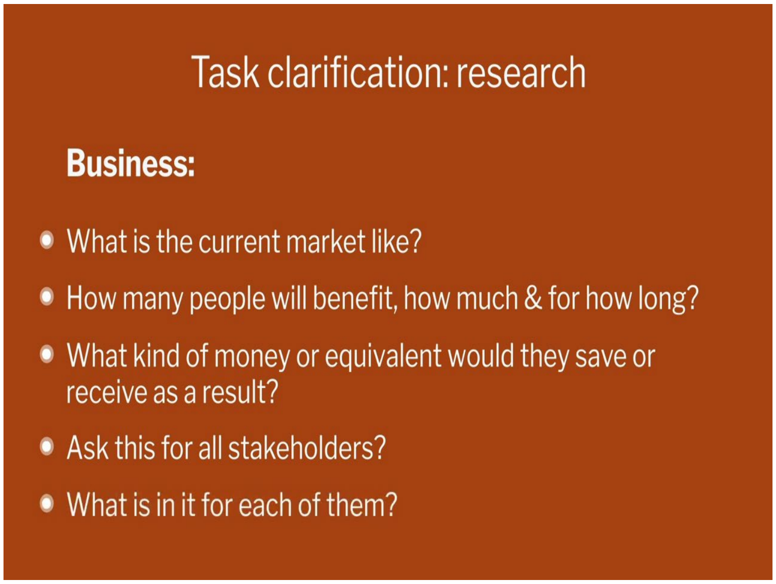

And finally what is the current market like, how many people would benefit if you did that. How much money is there for them to spare on this. What kind of equivalent the money that they will save or receive. And this is something that we need to ask for all stakeholders, not just the people who are going to pay. So, what is in it for each of them. So, basically the question is if you think of the entire process of taking your product from your head to the society, there is somebody who is going to do it, right?

There are multiple somebodies. Are all of them benefitting? If not all of them are benefiting somewhere the chain will break and I will give an example later.

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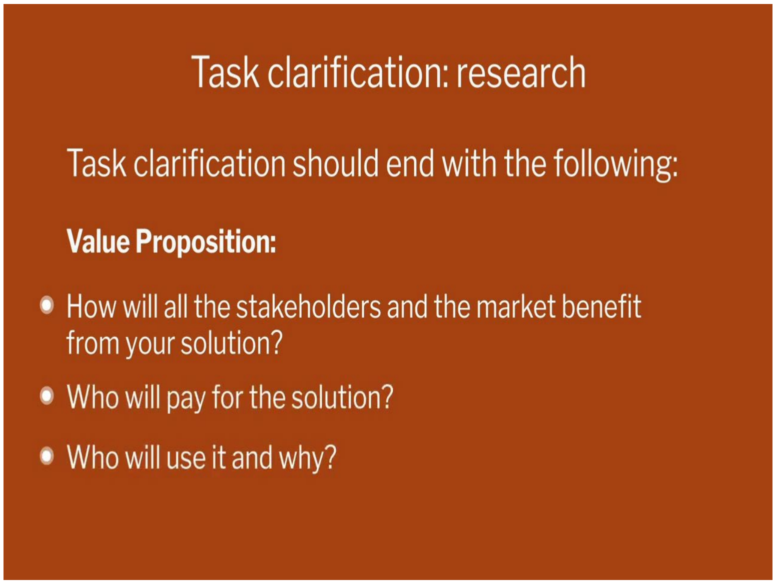

At the end when you have done all of that you should have a Value Proposition. So, you should have an understanding of: How big is the group of people? What kind of people? Who are the stakeholders? How will they benefit from the solution? Who will pay for the solution? Who will use it and so on. And why should they do that? What is the big deal for them?

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Second is a list of intents that your eventual solution must satisfy.

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And third is how important these intents are. If you ask people, 'What do you like?' They will say, 'I like this, I like that, I like this'. They like everything, but if you say, 'Ok which ones are you ready to pay for?' The number will come down dramatically.

So, you need to look at: What are the monetizable needs that are there? Which of them are essential? Which of them would be nice to have?

If you are designing a machine with which you are going to get a certain level of quality of cleaning on the floor then cleaning is essential, right? You cannot compromise that. There may be many other things that can be compromised but not that one.

So, there are some 'Essential' requirements and there are some 'Would Be Nice' requirements ok. It would be great if you can have these 'Would Be Nice' requirements as well but the 'Essential' must possibly be satisfied.

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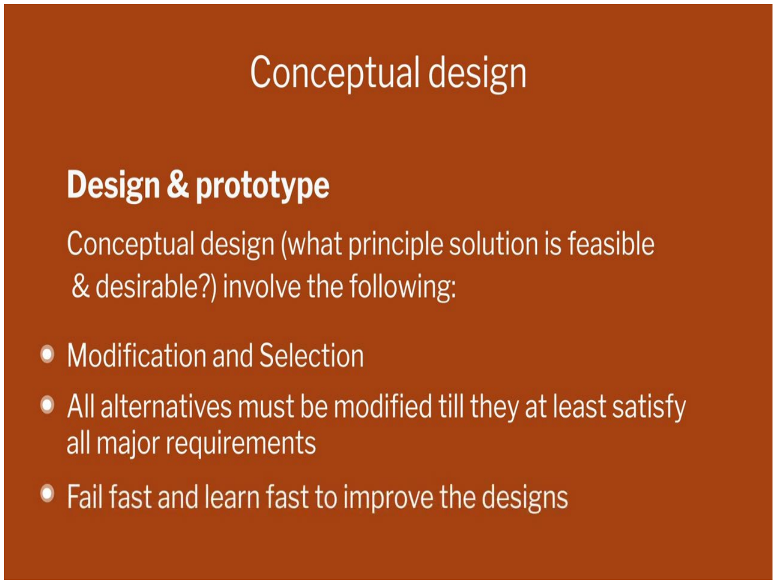

The second part is: Once you have created it, what is the intent of the product or solution going to be? You are then going to design and prototype it which we call Conceptual Design. So, what do you do there, you create multiple, alternative ways of, you know, satisfying those requirements. Normally, you know, you have looked at those examples, right? So, you can heat the cone, or you can put a wiggle motor, or you can just use a material that is more flexible and there are many other possibilities.

The important thing is to bring all these possibilities together, explore them, see which one works better, in what respect and bring them together. And do not get fixated to the first one. Do not have your favorite one. You have to have multiple alternatives and you need to model and evaluate all of them and see: Which one really works? What works? Fix the ones that do not. And eventually bring it to the same level, so you can compare them with each other. And so which one is really the best that I should go for?

And then select the one that satisfies all the major requirements, the one that you cannot do without. And also ensure maximum satisfaction of most of the other ones. We call those requirements that you cannot compromise ‘Demands’ and those requirements that you can but it will be nice to have ‘Wishes’. So, make sure that your solutions satisfy the demands and maximally satisfy the wishes. And one message here is that you should fail fast. It is good to fail actually. The more you fail and learn from it, and the faster you fail, and the cheaper you fail the more knowledgeable you become very quickly. So, fail fast, cheap and learn from it.

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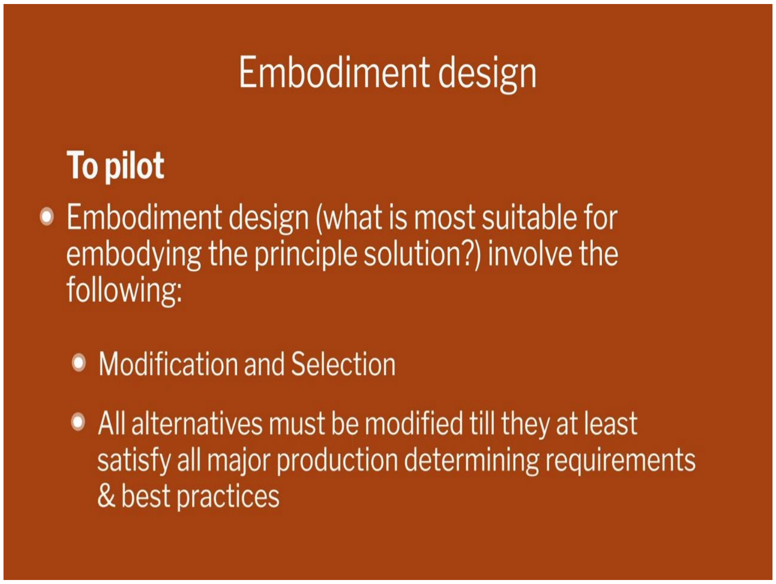

And then what we do is you essentially have come up with a principle that works. So if I take an example from primarily technical functionality, the basic principle on which a chair works is that it is a spring. That is a principle solution, that is looking at the core of what the chair is trying to provide and that is what you figure out. Of course that is not the only one thing to figure out, you have to distribute the load, you know.

The bottom of people are very different, each person's bottom is different and the chair has to cater for all of that. And then once you have done that, you can create a spring in a shape, and there can be zillions of shapes. I can have a chair that has only the backrest and the bottom rest and not the rest of the things, I can have one where there is a support at the bottom, I can have one where there is no backrest also but only resting just the body and so on. So I can have multiple Embodiments: Bodies with which I can embody the principle, right?

So, again you need to do the same thing. You need to look at multiple alternative embodiments now. Should the chair look like this? Should the chair look like that? And so on.

You need to again, model and evaluate the alternatives.
And now your requirements are becoming different. So what you are creating now is a spatial layout rather than the principle. So, you are focusing more on the components and the interfaces.
And you are looking at all kinds of other best practice requirements.
Such as reliability. It must do the same thing over and over again, that is reliability. You know, somebody sits here, goes back, somebody else sits here, goes back, all the time it must support the person, that is reliability.
What is robustness? Each chair is slightly different from each other. However hard you try to make something the same, it is not the same. Over that, however similar you think the environment is, it is not the same, right?

So, if I can vary the parameters with which an object is made, whether it is a size, whether it is a material, whether it is the production process, whether it is the quality of the interfaces with which they are connected to each other, the welding and so on. They are never the same.
So if I can make a lot of variation and yet the object functions, then it is robust.
Challenger was a space shuttle. So Challenger was going up, right? And it's O-ring, one particular ring that, basically a gasket to hold the fuel, that gave in.

The temperature on that particular Friday evening was particularly cold, and as a result the material went beyond the level of brittleness at which the thing gave in. Never happened (before), until that point of time. So, it was not robust enough to survive that range but robustness survived the first 22.

I just want to sensitize you to the fact that there are a whole bunch of requirements that are best practice requirements. You do not write it down, 'It should be maintainable', 'It should be safe'. Of course it should be safe.
So, you have to bring them together so that the part, the material, the implementation, the details are right enough that you will survive. Reasonably survive. And then of course it does not work the first times they keep fixing it until you are with that.
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Finally, you know, if you are happy with that then you can go to detailed design. The last of the 4 stages of design, where your intent is to make sure that it is produce-able in large quantities. So, once again your focus has gone from spatial layout to the components, the parts, the specific quality of the materials. So, focus is getting smaller and smaller, so I want you to now, here, focus on the detail of every piece.

Remember the O-ring. O-ring failed. That was a very complex spacecraft. Everything worked alright except one O-ring and why did it fail because it's bitterness was changed to a value which surpassed the temperature on that particular Friday night, so you have to be careful.