Introduction to Biomimicry
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Lecture – 35
Learning from the Biomimicry Process

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Case Study
Student Project

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Hello, everyone. Welcome to the case study on student projects. I am Shakuntala Natarajan. I am a student at the Department of Biotechnology, IIT Madras and I am here to brief you about a project which I had taken as a part of my introduction to biomimicry course, and I hope you like it.

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UN Sustainable Development Goals

Before moving into the details of my project, first let me brief something about what United Nations Sustainable Development Goals are. This constitutes a framework of 17 goals, which have various problems that are being phased in the world categorized into these 17 classes. And of these 17 goals, the UN SDG 12, which is 'responsible consumption and production' is what I have chosen as the goal for my biomimicry project.

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12: Responsible Consumption and Production

Ensure sustainable consumption and production patterns

TARGETS SELECTED	INDICATORS SELECTED
12.2 By 2030, achieve the sustainable management and efficient use of natural resources	12.2.1 Material footprint, material footprint per capita, and material footprint per GDP
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	12.4.2 (a) Hazardous waste generated per capita; and (b) proportion of hazardous waste treated, by type of treatment
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	12.5.1 National recycling rate, tons of material recycled

So, the 12th UN SDG which is responsible consumption and production, it deals with ensuring sustainable consumption and production patterns. So, each UN Sustainable Development Goal has a set of targets and a set of indicators. So before moving on to a problem and before solving a problem, you need to have a vision. You need to know what would be the final thing that you need to achieve.

So, the targets are very important in this sense. And the indicators will help us to assess to what extent have our targets been achieved and are we on the right track. So, in this aspect, I have chosen three particular targets under the UN SDG 12, which is target 12.2 which is about achieving sustainable management and efficient use of natural resources. And the next target is target 12.4 which says we have to achieve environmentally sound management of chemicals and all waste throughout the lifecycle.

And minimize their entry into air, water and soil regions and reduce their impact on human health and the environment as a whole. The next target 12.5 is about substantially reducing waste generation by 2030 by following the aspects of prevention, reduction, recycling and reuse. So, these are the targets that I have chosen for my project, which I am going to explain now.

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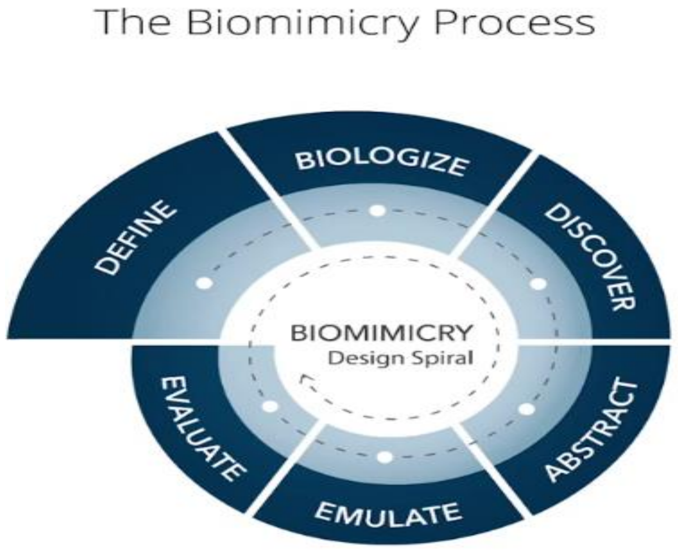

So, we are going to talk about this wonderful process called biomimicry. And as you can see, biomimicry constitutes of the 6 major steps which is define, biologize, discover, abstract, emulate and evaluate. So the entire process is being concisely depicted by this biomimicry design spiral here, and we will be looking into its details in the ensuing slides.

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So, the first step of the biomimicry process which I undertook was the define step, to define the problem which I wish to address. So before tackling any problem, we need to first define the problem correctly and get it scoped perfectly so that we will be in the right track in our solution and we will achieve our vision or goal in a positive manner. And to tell you the truth, this was the hardest step of all the 6 steps for me in this process.

It took a lot of time to exactly arrive at a good problem definition so it gave me a nice freedom to explore the problem statement as well as to not deviate from it. So your problem statement needs to be within a boundary that gives you enough freedom and as well it should also help you in not deviating outside the boundary. So, considering these aspects, I came up with the problem statement and a question.

Which goes like how might we develop a safe and sustainable solution for packaging to reduce plastic footprint and facilitate better waste management in developing countries? So this was the question problem definition which I had put forth before starting the project. And I would like to give you some perspective on why this is an important problem to tackle in the current scenario. So as everybody knows plastic pollution is plaguing the entire globe, it is causing great environmental harm.

And plastic has been ranked as second in the ladder of global wastes only after food waste. And there is also a dearth of efficient plastic waste management practices, especially in developing countries due to the economic complexities involved as well as the low recyclability rate of plastics adds fuel to fire. And moving on stringent bans on single-use plastics have also been imposed especially in developing countries as well as in developed countries.

And since most of the packaging materials are made up of single-use plastics, this sector has been greatly affected. So, these taken together provide an impetus for devising eco-friendly alternates for plastic packaging and these form the basis of my project.

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So, once the 'define' step was done, the next step we moved on to was 'biologize'. So, in biomimicry, what we do is essentially, we learn from nature. So, if you have to learn from a person you need to talk in the person's language, right. So, you need to talk with nature in his or her own language. So, to do that biologize is the catalyst which helps you accomplish this process.

So, in this step what I did was I searched for the functions which would help me in arriving at a good solution for my problem statement and those functions must be present in nature. So, I searched for these functions in nature. So, what are these functions which I searched for were pack, cover and protect from external stress, remain structurally strong, undergo natural degradation and it must be nontoxic and safe. So, based on these functions, what I did was I again framed them into question as in how does nature pack or store?

How does nature assemble or degrade substances? How does nature protect from external threats? So, formulating your ideas in the form of questions helps you get more clarity in the process and this will help you transition to the next step more easily. So, how does nature do the function which I want to accomplish was the basis of this biologize step. Essentially, I translated my needs in the language of nature, which helped me move on to my next imminent step, which was 'discover'.

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So, discovery is something exciting, right. So, the process of discovery in the biomimicry spiral process was also exciting for me since it gave me a lot of opportunities to look at very smart organisms, which had evolved on Earth and they had developed some super cool strategies, which were in fact mind-blowing. And let me explain about the organisms which are used for a project here below. So, the first organism which I looked at was the Chinese paper wasp. As you can see, you are seeing the wasp's nest here.

So, what this wasp does is it has its saliva, the saliva has hydrophobic proteins. It combines its saliva with the plant cellulose material, so the plants structural materials they are made up of cellulose and hemicellulose. So, this wasp combines its saliva with the plants material and this gives rise to a hydrophobic water repellent, biodegradable nest, which it is used to stay during the rainy season. So, you can see the picture there and that is how the wasp survives during the rainy season.

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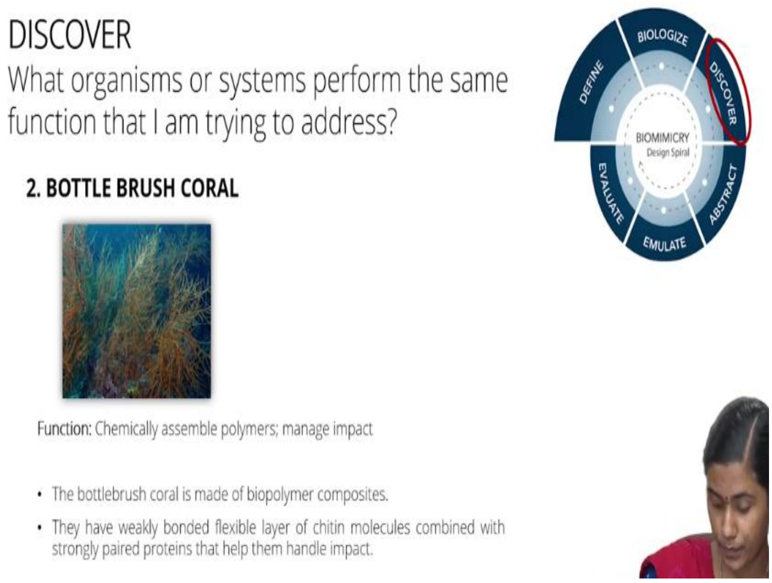

And next interesting organism, which I looked at was the bottle brush coral. So, the name sounds cool, right? So yeah, and the organism is also cool. This coral is made up of biopolymer composites and it has a very peculiar arrangement of these composites. So, it has weakly bonded flexible chitin molecules in one layer and it is combined with strongly paired proteins in the other layer.

So, the flexible layer and the hard layer, they are arranged in an alternate manner giving rise to a complex biocomposite material that makes this coral as a whole. And you might be thinking what is the necessity to have such a configuration? And the answer is this coral resides in the sea where it is subjected to external water currents and forces and it needs to withstand them without breaking.

So that is the reason this coral has evolved such a beautiful polymer arrangement and this is the function performed by it in chemically assembling polymers and managing impact, so it is able to manage its impact that rises out of the forces coming when the water current flows through.

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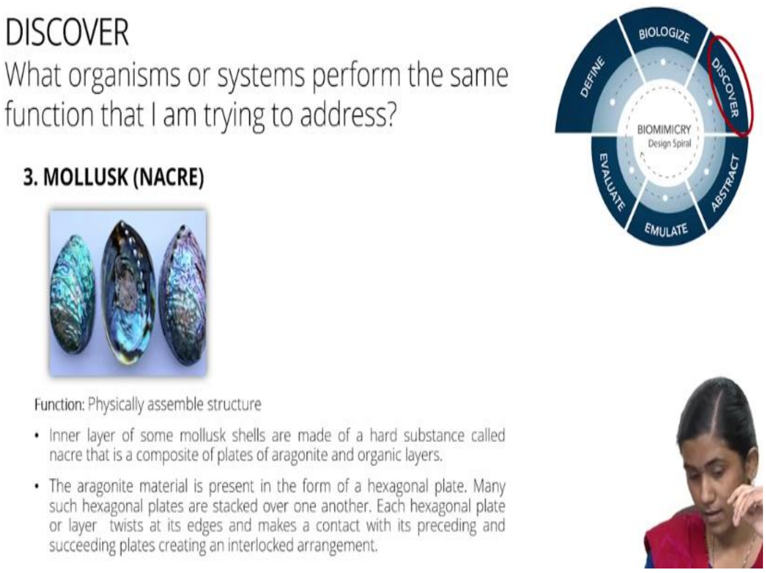

And next organism which I looked at was the mollusk, the mollusk shell to be concise. The inner layer of this mollusk shell is made up of this hard substance called the nacre. The nacre is made up of two other materials and one of the materials which is of important focus here is aragonite. Now aragonite is made up of hexagonal plates and these hexagonal plates are stacked over one another and they also interlock with one another in a stacked arrangement. So, this gives rise to an interlocked arrangement for this shell making it extremely hard and resistant to external impact, so it does not break.

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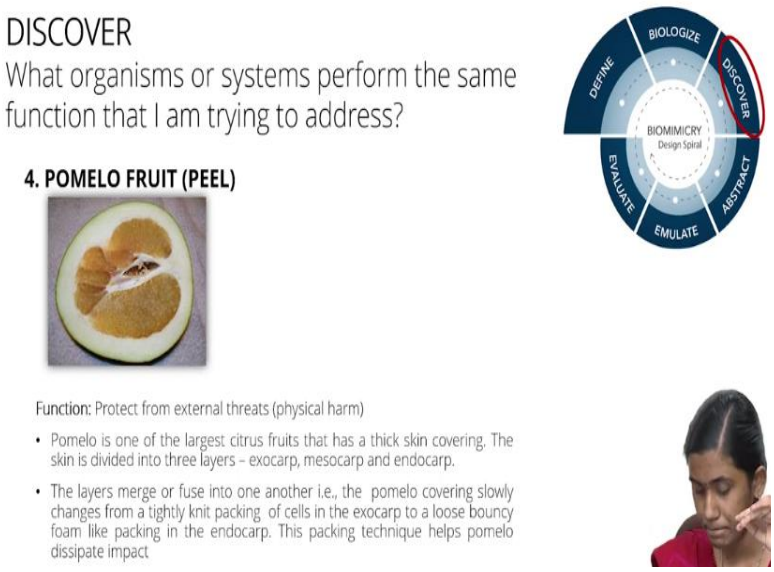

And pomelo fruit peel was the next example from nature that I looked at. So, this is one of the largest citrus fruits and it has a thick skin covering. And what we all see is when a fruit falls from a tree, it undergoes some damage, right. But pomelo has evolved a very beautiful mechanism wherein if it falls from even about 10 meters from its tree branch to the ground, it does not break up and the secret behind it staying so fit and healthy is that it uses this technique of fused layers.

It has three layers called the exocarp, mesocarp and the endocarp which are technically the external layer, the middle layer and the internal layer. So, these three layers fuse together and they are not distinct. So since they fuse together and support each other, they are able to distribute the impact that is felt by the outer layer till inside, so they are able to distribute the tension towards the inner layer.

And they are able to manage the resistance and the force that comes from outside. So, that is the reason why pomelo fruit is resistant to external impact and to fall from such high distances.

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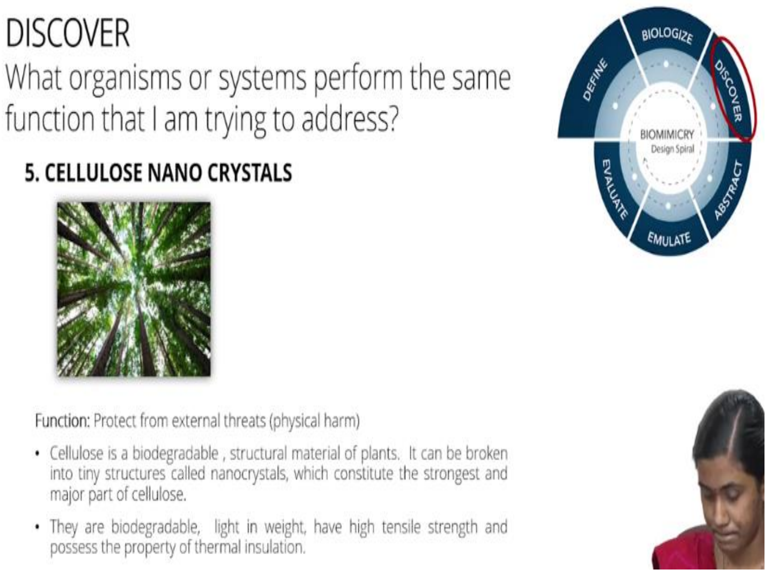

And the next organism which I looked at was the cellulose nanocrystals from plants. So, cellulose is the structuring material of plants and it is responsible for the structure which we find in the plant kingdom. And all cellulose has this property of structural maintenance, mechanical strength, etc. There are some excess properties for these nanocrystals of cellulose. Since they are very tiny in nature, they also have extra attributes like high tensile strength and property of thermal insulation in addition to mechanical strength. So, that is an added-on advantage for the cellulose nanocrystals found in the natural kingdom.

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This is something that I found extremely interesting. So, this is a bird called Clark's Nutcracker. This bird what it does is it stores its seeds, it collects its seeds and it does not eat them. It has to take it for its offspring or let us say it has to travel long distances and give it to its children. It has to store it somewhere, right. So what it does is it transfers the seeds to its throat pouch. You are able to see a bulged appearance there right, so that is the throat pouch of that Clark's nutcracker.

It stores the seeds there and while it is putting the seeds in the throat pouch expands like a bag to hold all the seeds. And once it reaches its place, let us say once it reaches its offspring and it wants to feed those seeds, it is able to take out the seeds and the throat pouch again shrinks to its normal size. So, it is like an expandable pouch, so that is the mechanism which Clark's nutcracker has evolved.

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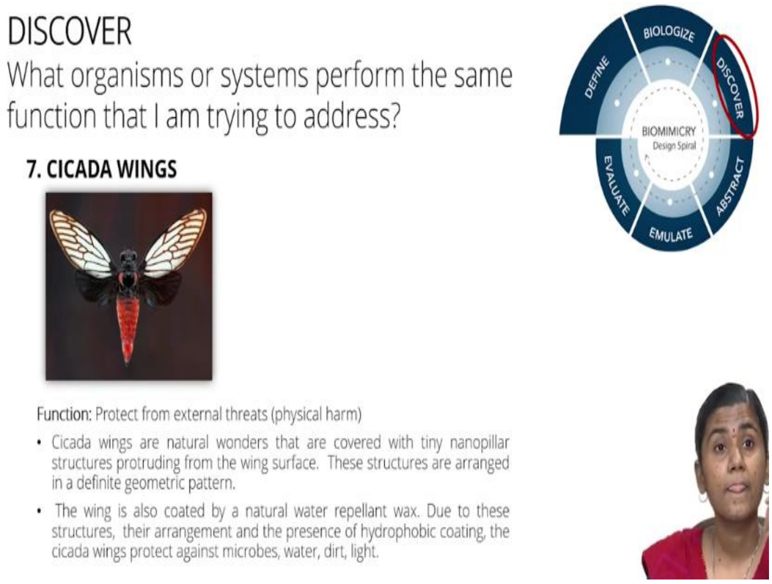

And the last organism which I looked at was the wings of this insect called cicada. So, these wings are phenomenal in nature. So, they have very unique properties and the properties are the wings are covered with tiny nanopillars which helps in preventing microbes from settling on wings, so it is antimicrobial in nature. And they are also coated with a natural wax like material which is water repellent making them hydrophobic and this prevents settling of dirt on the wings.

And also due to the arrangement of these nanopillar structures, the wings are also able to deflect light. So, it makes the insects wing free of light and helps it in escaping from predators. So, this is the mechanism that has been used by the cicada insect.

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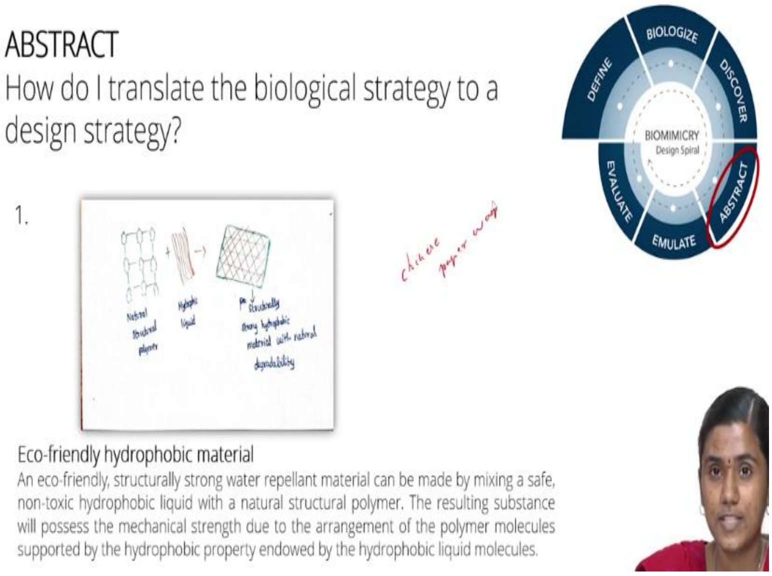

Yes, so after the discovery step, the next step in the biomimicry design spiral is abstract. So abstract is something where we shirk off all the biological terms that are associated with whatever organisms we had looked at till now. We are extracting the design aspects from the organism and we are translating it into a language so that we will be able to use it more generically in the human realm to solve the problems existing in the human body. So, that is what is the crux of this abstract step.

And the first design strategy which I abstracted was about an eco-friendly hydrophobic material. So, we can obtain an eco-friendly hydrophobic material that is structurally strong, how by mixing a water-repellent hydrophobic material with structural material which is naturally biodegradable. So, when these substances are mixed together, they will give rise to an eco-friendly material that is able to biodegrade as well as repel water in a concurrent fashion.

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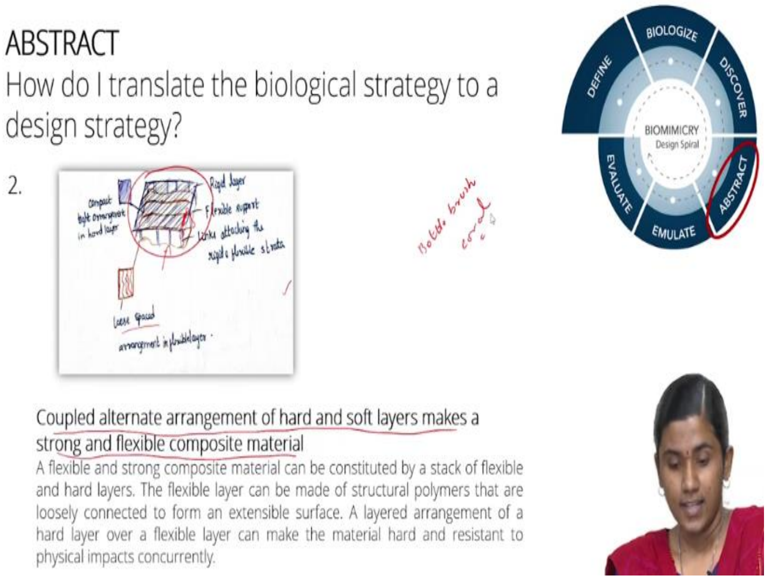

So, the next design strategy which I abstracted was about coupled alternate arrangement of hard and soft layers makes a strong and flexible composite material. So, this is something very interesting. So, what happens is, so this is the arrangement that you can see here and there is an alternate arrangement of the flexible layers, say the flexible layers make up the first layer and the hard layer makes up the second layer.

So, when these are combined together, they give rise to a very nice composite material that is able to extend under stress as well as stay strong when it is disturbed with external forces. So, that is like hitting two mangoes with one stone. And as you can see, the flexible layer is made up of loosely spaced the fibres which are arranged with good spaces in between as shown by the lines here. And so these help the material to perform in this bifunctional way. So, this is the second design strategy which I abstracted.

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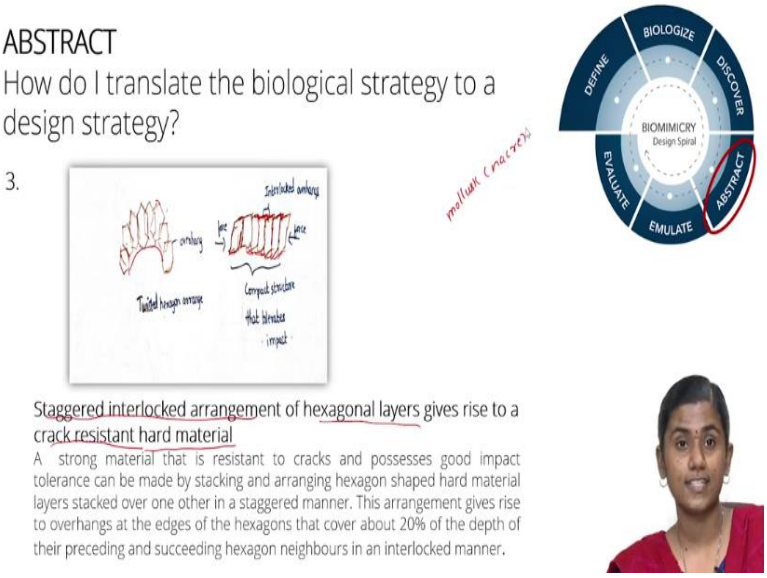

And the next design strategy is something very nice. So, this is concerning a staggered interlocked arrangement of hexagonal layers. So, such an arrangement of these layers gives rise to a crack-resistant hard material, so that is the aim. To arrive at a crack-resistant hard material was the design strategy and this was accomplished by arranging these hexagons in a twisted manner, as you can see in the picture here in a twisted manner.

And when they are twisted in such a manner, you are able to see the overhangs about and the overhangs below. So, what happens is when they are pushed together in a stack, the overhangs are able to interlock with each other, and they create a coupled interlocked arrangement, which prevents them from moving here and there when the external forces come in and they are able to stay strong together. So, that is the basis of this design strategy.

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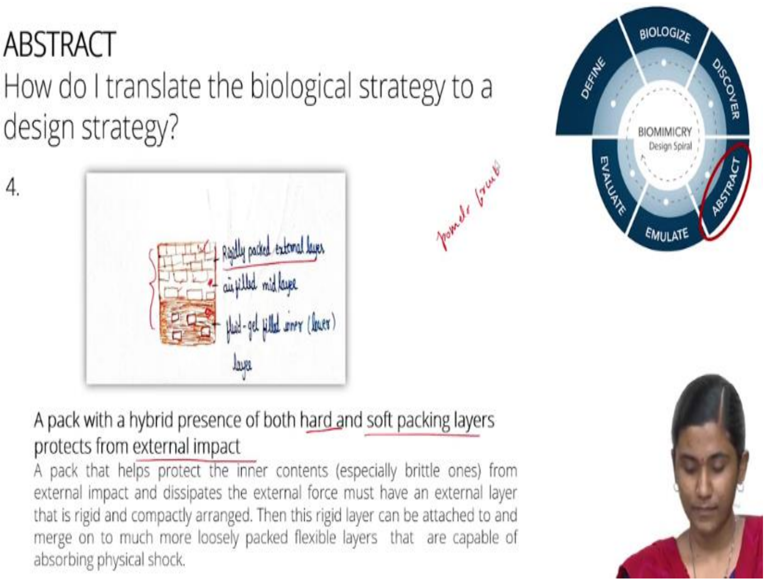

And the next design strategy is about a pack that has a hybrid presence of both hard and soft packing layers and such an arrangement helps and protects them from external impact. So, as shown in the design strategy here, so you have a rigidly packed layer outside where you are able to see the cells closely packed.

And then the next layer has the cells which are loosely spaced out and the next layer has some fluid filled in between, most of the space is taken up by the fluid and very little space is taken up by the cells. So, this creates a very rigid to a very loose arrangement sort of strategy and this helps us arrive at a structure that protects from external impact and resist them simultaneously.

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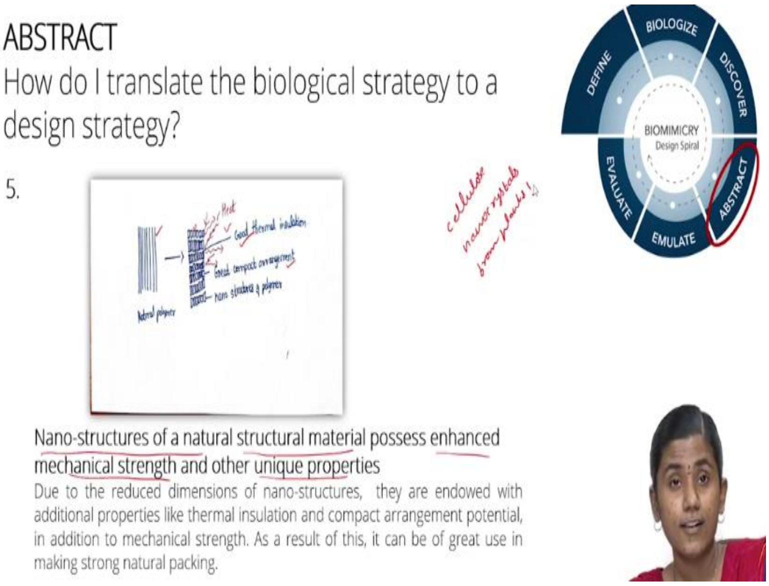

So, the next design strategy which I have abstracted is about nanostructures of natural structural material, they possess enhanced mechanical strength as well as some other unique properties. So, this is a natural polymer and as you are able to see the structures are present in long dimensions, they are large. Now, let us say we are cutting them into bits, let us imagine that these are nano dimensions. And so, I have obtained nano dimensions of this natural polymer, and as you are able to see these nanostructures of this natural polymer.

They have excellent properties in addition to the natural mechanical strength that is obtained from the parent material. In addition to their mechanical strength, they are able to give good thermal insulation, they are able to have a great compact arrangement and they are able to withstand heat. So, these are the additional properties that have been attributed to this material when it is present in its nano form. So that is about this design strategy.

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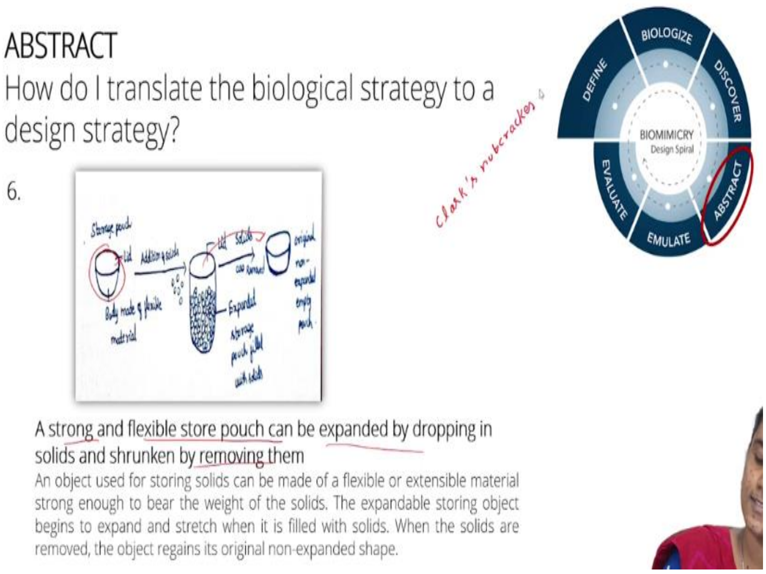

And the next design strategy is about a flexible store pouch that is strong and that expands when it has solids in it and shrinks when the solids are removed. So, let us say this is the pouch, and I am adding some solids. Let us say I am adding candies inside. And when I add candies inside this pouch expands like how a balloon expands when we give air. And let us say I need to take out all those candies for eating and now I am removing all those candies. So, when I remove them back, the pouch shrinks back again like how air goes out of balloon when the opening is moved out. So that is about this design strategy.

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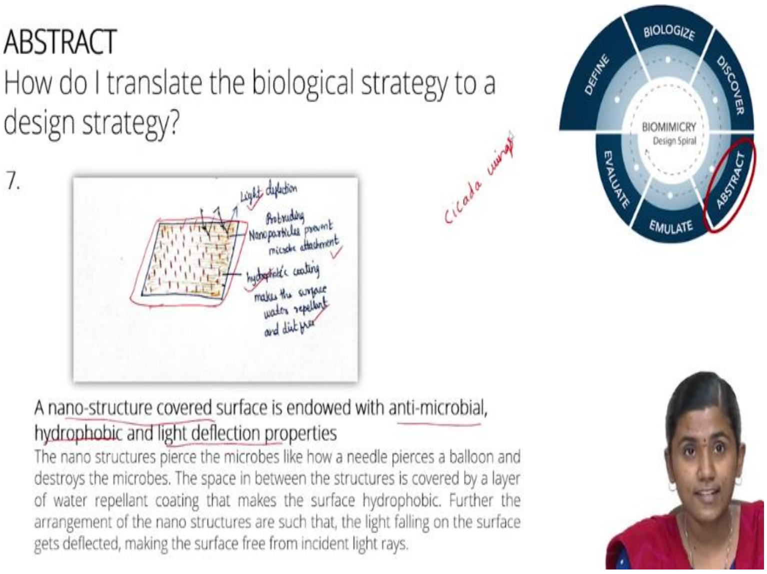

And the last design strategy is about a surface, a nanostructured covered surface that is endowed with the properties of antimicrobial resistance, hydrophobic nature and light deflection. So, this is the surface, the yellow-colored rectangle is the surface you are seeing and the red lines are the nanostructures that you are seeing and the protruding nanoparticles, they pierce the microbes which are trying to enter and they destroy the microbes thereby giving antimicrobial attribute.

And in the space that is remaining between these nanopillars there is the hydrophobic coating that makes the surface also water-repellent and dirt free. And due to the arrangement of these nanopillars optically, they are in such an arrangement that they are able to deflect light simultaneously. So, all these properties are being satisfied by a mere physical arrangement of these structures are present on this surface, which gives us this hybrid and super-performing structure.

I have shown you all my design strategies, but I think it would be great if I am giving you an idea of each of the organisms from which each of these design strategies has been abstracted that can give you a better idea of how this abstract step has been done. So let me start from my first design strategy. So, this eco-friendly hydrophobic material I abstracted it from this organism, does anyone of you remember all the 7 organisms which I told?

I know it is a huge list, but you please try to recollect them and here I am giving you the list anyway. So, the organism which I abstracted this from was a Chinese, what was it, Chinese paper wasp, yeah. So, remember the next we saw that was the inspiration for this strategy.

And this strategy of coupled alternate arrangement of fibres, this I took it from our cool friend which was the body brush coral.

And yeah, this hexagonal arrangement, so can anyone of you remember what organism this was from? A very shiny picture which I showed you, yeah it was from the mollusk nacre, the shell of mollusk nacre. So remember that shiny hard shell, so that was the inspiration for this design strategy. And this is from our great fruit, yeah it was from the pomelo fruit, the large fruit that does not break even if it falls from height of 10 meters.

And the nanostructures design strategy was from the cellulose nanocrystal obtained from plants. And this wonderful expandable pouch strategy was from our friend, which had a very innovative throat pouch structure. I guess you must have guessed it by now yes, it is Clark's nutcracker. And this wonderful surface which has so much properties combined in one this was from our tiny friend, yes it was cicada, it was from the cicada’s wings.

Pretty interesting, right? So many strategies from tiny organisms around us and they are so marvellous in nature. So, we are now done with the abstracting of design strategies. Now, let us move to the prefinal step which is emulate.

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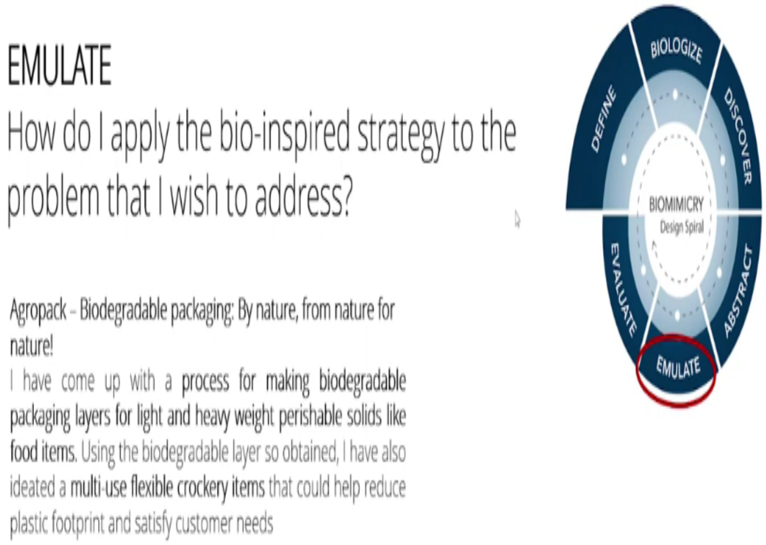

So, this is the stage where I am going to tell you about what I have arrived at exactly after going through this process. So, I have come up with something called Agropack which is biodegradable packaging material and so that attributed a few classes to it. So it goes like by nature, from nature and for nature. So, that is the tagline I had kept for my solution. Let me explain briefly about it.

So, by following this process of biomimicry, I came up with a process for making this biodegradable packing material that is suitable for both light and heavy weight perishable solids like food items. And I have also arrived at a solution using this biodegradable layer which can be used as multi-usable, flexible crockery that can in turn help us reduce the plastic footprint.

Remember that was one of our targets under the UN Sustainable Development Goal 12 to reduce waste management by 2030 in an efficient manner by attributing to recycling reducing and things like that. So, I focused on reducing the plastic footprint while simultaneously satisfying customer needs. So, this is an overview of my solution and let me show it to you pictorially.

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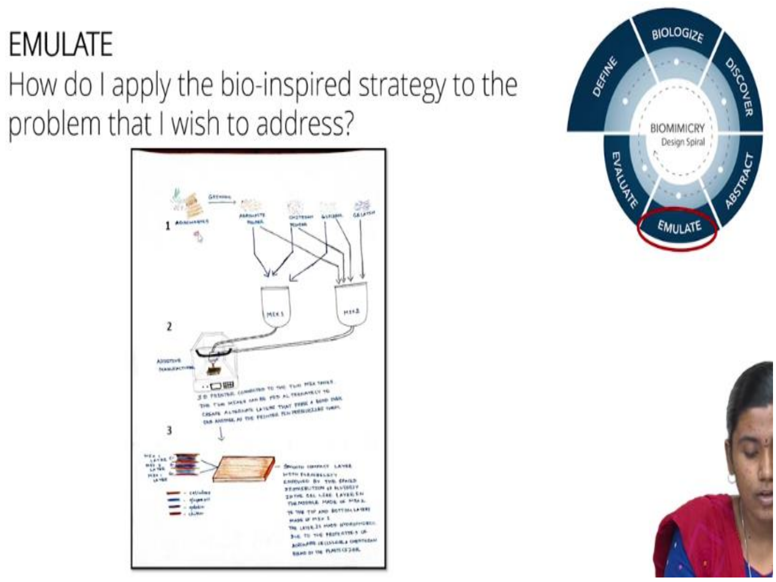

So, I have depicted my entire process here in the ensuing slides and I will take you step by step through it. So, the starting material for my solution are agro base. So, they are basically biobased agro residues of crops that are remaining after harvesting, for example, corn husks, rice husks, etc. They are excellent sources of cellulose, hemicellulose and are hence structurally rich. And the next impending step is to grind them and get a powder, make a power of them.

Now, the agro base powder is my starting material. I mix it with chitosan powder, glycerol and they make what is called mix 1. So, this is mix 1 which is sent to us separate tank and the next mix is made up of agro base powder, chitosan powder, glycerol as well as gelatine. So this will help me make my mix 2. Why mix 1 and mix 2? Mix 1 basically contains all the structural materials along with the binding agent glycerol, so this will help me get a hard layer.

Whereas mix 2 which has gelatine also in it helps me arrive at a flexible layer. So mix 1 helps me get at a hard layer, mix 2 helps me get to a flexible layer. Remember which organism I used for getting this design strategy, yes this was from the bottlebrush coral. And the materials of this pack which is agro-based powder and chitosan powder and flexible material of gelatine. I arrived at these materials by comparing the materials used by the Chinese paper wasp for making its nest.

It uses its saliva which is hydrophobic in nature and it resembles chitin. So, the natural realm if chitin is the molecule, then in the human realm we are producing chitosan powder which is readily available. So that was the spark behind arriving at the constituents of these mix 1 and mix 2. So now this mix 1 and mix 2, they are sent to this additive manufacturing unit which is nothing but a 3D printer and the mix 1 is first layered given a source for this 3D printer.

And it layers the layer 1 and after that the mix from the mix 2 tank is sent over it and the flexible layer is kept upon it and so on. So mix 1 and mix 2 they are layered alternately and they give rise to this wonderful material that is both hard and flexible at the same time. So, as you can see, I have depicted the mix 1 and mix 2, mix 1 and mix 2 alternately in different colours in step 3.

So, this is a smooth compact layer, which helps us distribute external tension and impact in a very even manner. And the appearance of it also looks very smooth since it has been produced by additive manufacturing process, which is an industry 3.0 process. It is a very modern process, so it helps us arrive at a material that has a very good finish.

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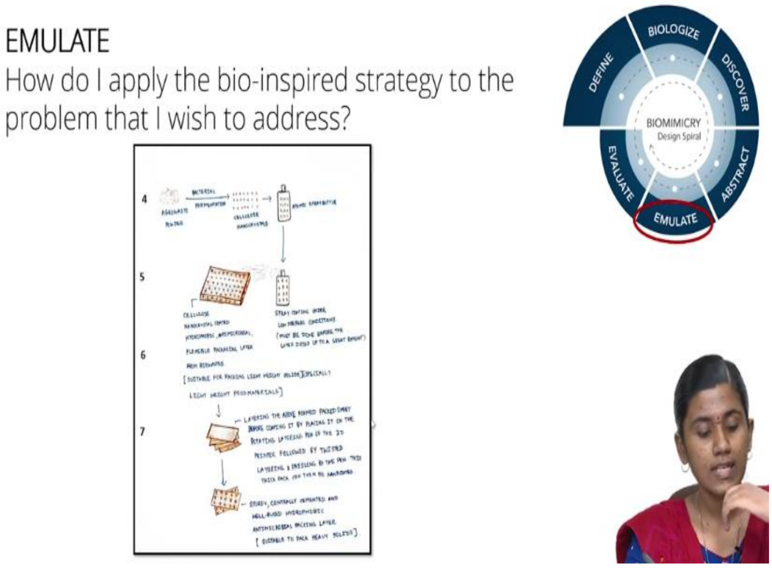

So, the next step after getting a very smooth layer, so for packing material for packing something like food material, the pack should be hydrophobic, it should not allow microbes to attack and things like that, right. So, in order to give these attributes to my pack, I have again added these steps. So, again the starting material is our agro-based powder. I subjected it to a process called bacterial fermentation.

So, bacteria like cellulose that is the food for bacteria. So, I subjected them to bacterial fermentation in bioreactors. And the products which get out the remnants, the remaining agro based which are chewed out, after the bacteria eat them they are cellulose nanocrystals. These cellulose nanocrystals are being produced by the bacteria. These cellulose nanocrystals can be compressed in a bottle, for representation sake, I am saying it is a bottle.

Let us say I am taking all the cellulose crystals and compressing them in a bottle ad this I call the atomic spray bottle where I am storing them under some pressure so that they are all concisely put together. Now, when I relieves the pressure and they apply these cellulose nanocrystal to my pack material, these nano crystals go and settle down on my layer. And the important step is that this step of spray coating must be done before my layer entirely dries up, else my nanocrystals would not get fitted properly on to my layer.

So, once these nanocrystals are coated and my layer has dried up with these nanocrystals in place, I am now able to get a whole packing material that is flexible, which is resistant to external impact, which is antimicrobial, which is hydrophobic in nature because of the presence of these nanocrystals and it temporarily helps me in putting perishable items within this pack material.

So, the inspiration for getting this nanocrystal-coated surface was from the cicada wing, which had all the properties on its wings surface at once, so that was the inspiration to get this. This is for normal perishable solids. Let us say we want to pack chips or very light food item, let us say we can use this material, but what about very heavy items? What can we do for that? In that case, the back material needs to be much more sturdier.

So, in order to do that nothing needs to be changed chemically, a very simple twisted arrangement of my spray coated layers. When I arrange them in this twisted manner as we had seen for the arrangement of layers in the mollusk shell, if we just do this physical manipulation and again stick off all my layers like this in a twisted arrangement and interlock all these edges, the remaining edges that would give rise to a very strong material that has this interlocked arrangement and it is suitable to pack heavy solids as you can see here.

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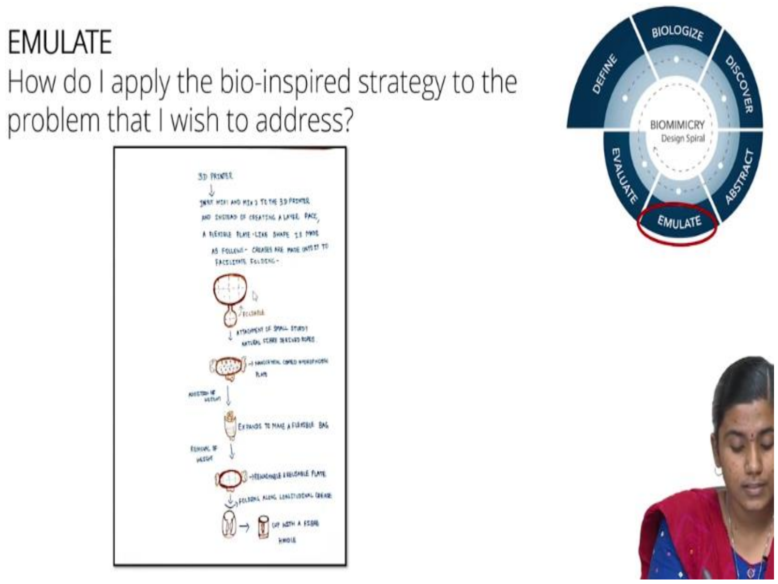

And this is the next solution which I told you about multi-usable, flexible crockery. So what we are doing now in the current world, we are using paper cups, plastic cups, plastic plates and we are buying them again and again. So you are using plastic for making a cup, you are using plastic for making a plate and you are using plastic for making a spoon, right. But imagine how it could be if you can use your plate as a cup and your cup as a bag.

All in one that could save you costs as well as it will save material production and consumption that will help us balance out our production and consumption rates too that is where this solution comes in. So, this solution is about the base material is again my agro base powder. It is combined with my materials which I told before, gelatine and things like that, and the step until getting a smooth layer is the same.

Now instead of making a rectangular layer, I am making a circular layer with a very small foldable flap. And I am attaching the natural fibre-derived ropes to this structure. And this is a plate which we can hold. And now let us say I want to go for shopping. Now I am putting some solids inside this. And as I put solids, the plate gets compressed and the ropes come close and you can hold the ropes together like a shopping bag.

So this inspiration was derived from the Clark's Nutcracker, the one with a throat pouch, so that is akin to the shopping bag here. And once I remove my weight, let us say I am done with my shopping and I want to have some coffee. So, I now go back home and I remove all my weights or my shopping items and it is again that in the form of a plate. Now no worries, I again have this flap, the ropes on the sides.

I can join them together like a seal and I can hold the ropes like a handle and the plate already has a flap for the base support and I can easily fold it up like an organic cup and I can have coffee in it. Since it is hydrophobic, it is anyway not going to absorb my coffee and make any changes to it. So that is the multi-usable, flexible crockery idea for you.

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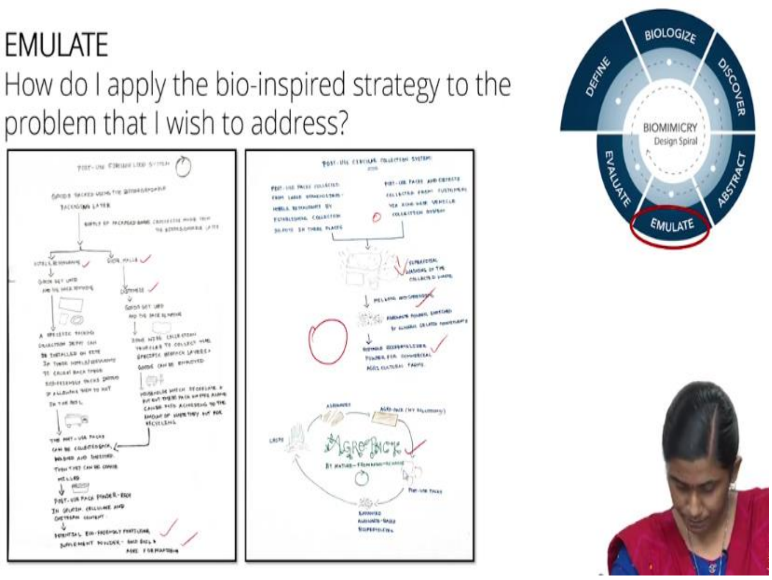

And post use, so everything that is concerning nature and that is getting inspired from nature has to resemble nature, right, so nature does not do any wasteful process. So what I did was after ideating these solutions, you cannot leave it as such, you cannot leave them to rot in the soil. You have to close the loop and getting a closed circular loop must be the ultimate aim of such eco-friendly processes.

So, I came up with a very small framework wherein these, let us say my products of the plates and things like that, my packing material, they are getting circulated to hotels, restaurants, shops, and malls as well as customers. And they have used them. Let us say their use life is over and I have devised some strategies to collect them from these zones. And once they are collected back, remember these materials were made up of agro-based gelatine, and glycerol which are very eco-friendly.

And when shredded down, they can hold water in a good manner. So, they can potentially serve as an eco-friendly fertilizer material. So, once I collect them from my customers after use life, I subject them to a very superficial washing process and shredding process after which they can be packed in the form of biofertilizers and sold to farmers. So, initially, my source material comes from the farm and goes back to the farm and is completely circular. So, that is what my solution Agropack is about. So it is by nature, from nature, and for nature for you.

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So, after the emulate step, evaluate is a very critical step. So, as I told you before, define was the most difficult step for me and after define, evaluate was the next difficult step for me because I had to revamp my initial thought process, my initial assumptions about how my solutions could work and this helped me arrive at the final structured solution, which I explained to you shortly before.

So, how I was able to do that was that I followed some of nature's design principles. So, nature recycles all materials. So, by taking cue from that, I created a post-use circular loop for my solution which was in the form of the biofertilizers, packed biofertilizer. And the nature uses chemistry and materials that are safe for all living beings. So, my solution as you can see was made up of agro-based powder, gelatine, glycerol which are very safe and eco-friendly materials and that do no harm.

And nature is locally attuned and responsive. So, these agro wastes have to be procured locally from the farming region, from the type of crop that is suitable for each region. So, my solution will be locally tailored and it will get raw materials from the local aspects and it is will suit the needs of the local population there. And so, the further steps, the next ensuing steps to implement and deployment solution in the real world are as follows.

A physical and chemical characterization study and structural assessment of these packing materials must be performed. And lab-scale experimentation on 3D printing aspects, this is additive manufacturing, which is a bit modern, so it needs to be experimented further. And something called the atomic spray-assisted nanoparticle coating technique is also a very new technique and its application in this field of packaging is also quite novel, so this has to be tested further.

And external environmental impact assessment studies need to be conducted as in how much temperature is this able to withstand, how much water is it able to withhold, or something like that such external factor impact assessment studies need to be done followed by most importantly degradability testing, in how many days does my material degrade so that is very important to standardize and experiment out.

And the final step would be to prototype it, get feedback from stakeholders, then further refine my prototype and scale up and take it up for final market entry. So that is my biomimicry project for you. And this is the whole biomimicry process. Thank you so much for listening to me and I hope you enjoyed the biomimicry process as a whole and the project. Happy biomimicry jaunt. Thank you.