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W6L29_Bead Microscopy (Guest lecture) Dr. Procheta Mallik (ISPF &ThinkTac)

Hello everyone, my name is Procheta Mallik. I work for an organization called Think-Tac, as well as an NGO called ISPF, where I'm a trustee. I would like to thank Kaustubh and APU for inviting me to this NPTEL course on I-Think Biology. And I'm going to be talking about the BEAD microscope. Just a little bit of background about our organization.

So Think-Tac has been working in the space of science education, and we have done STEM learning in the classroom with schools and so on. And we've been doing that for the last eight or nine years. The idea is that children get to learn better and more engaged through experience. So we have a whole repertoire of hands-on science and maths activities, where we share materials, content, etc with kids and they do various activities, experiments, and modes, and are in the classroom. And then they make observations and learn from those activities. We've been around since 2014. We started, as I said, as an NGO called ISPF.

And in 2017, we launched Think-Tac to work with private schools. So ISPF works with government schools. Think-Tac works with private schools. And then we also associate closely with the Raman Research Institute Trust. So we happen to be based out of Sir C.V. Raman's old home in Maleshwaram. We conduct the hands-on national science contest called the Raman Awards annually. We have a lot of faculty from APU who come and interact with the kids a do the judging and all that at that contest. So it's a very, very interactive, fun event. We, of course, work closely with schools, with CBSE.

We partner with them in taking science to more and more schools. We have created a bunch of content that's available on the Deeksha platform. We have M.O.U.s signed with states so that we can work with the government schools in various states. So in Karnataka, Uttarakhand, Telangana, it's already started. It's about to start in Maharashtra, Gujarat as well. And like this, moreover the next few years, we hope to reach more and more children with more engaging hands-on science activities. We also work closely with publishers, universities, with research organizations to make our understanding of how education works as well as create activities that we can take into the classroom depending on the subject.

Over the last eight, or nine years, we've had large insights into the education space having worked in a variety of situations in the sense that we work with government schools, we work with private schools, we work with English medium schools, we work with state vernacular schools, and that's given us the kind of insights that we need to understand what is required in the education space. Almost universally, there is some need or sometimes a major need for doing something engaging, hands-on, and practical in the classroom, which is missing, largely speaking, in our education system. So that's where we were kind of inspired to take activities into the classroom a work with the system in the sense that it connects the curriculum to activities and see how children can learn science in a more interactive, hands-on way. So that's how we've created hundreds of activities in science as well as maths, and we use those, map them to the curriculum, and use those in the classroom either seven or ten or fifteen activities over the year and see how the children make with simple materials, do observations, and conduct experiments on each of these activities. One of the activities we use is of course the bead microscope, which I'll demonstrate to you later.

But just a little bit of ground about the microscope itself and how it came about being used through history, actually, of how we've seen some things that are very small using just a glass lens, right? So that's how it started. There's a simple microscope which is either a glass lens or a glass bead. All of you may have used a magnifying glass to see something bigger so the idea is to have a convex lens that diverges the rays, and you get to see a magnified image. Now, the smaller that bead is, the greater the magnification at a smaller distance, and so that's the whole concept of how microscopes work.

Simple microscopes work with a small glass bead, which you keep very close to the sample, close to your eye, and that's what we make with children. Of course, the compound microscopes that you have in your labs have an arrangement of two or more such lenses, and that creates even larger magnification. But as you can imagine, slightly tougher to make. So there's this video by Professor James Gall, quite a famous class that he did for about 20, 25 minute YouTube video. You can watch it, and he talks about the whole history of how the bead microscope has been used, and how various things have been discovered over the last 200, and 300and years using just a simple glass bead microscope.

So the use of a magnifying glass or a bead to enlarge objects behind it has been going on for the last maybe five or six hundred years. 1400 is kind of the first document of people using it to magnify images. The compound microscope itself, we don't know exactly who invented it. It could even be Galileo. I mean, we certainly know that he invented the telescope, but the microscope itself, there's no real document of who it was exactly, but it was probably around the same time, around 1600, and sometimes attributed to Galileo himself for having used a compound microscope.

That is, two beads or two lenses kept along one focal plane with each other, and to see from along one axis, and get to see an image after the second lens. So you have an objective and an eyepiece is what we call them, and you get to see a magnification of the product of the two lenses, the magnification, which we'll talk about a little bit later. There are various people like Robert Hooke. You know that the spring law, there's Hooke’s law, but he is also very interested in biological specimens. He's supposed to have used a bead microscope early on and had this beautiful book called Micrographia.

There's another Dutch textile maker called Leeuwenhoek who used these simple bead microscopes to look at textiles, and then he actually also saw insect specimens, and he's also drawn these, and he published it with the Royal Society and so on. So he kind of became famous and is sometimes called the father of bead microscopy because he used these small glass beads to act as magnified images of various specimens. And it so happens that the cell that we see, an onion peel cell that I'll show you a couple of videos, and we'll even try and see it live through my phone, using one of these bead microscopes, that was first observed using, again, a single simple, what we call a simple microscope, which is a single lens bead, and that was by Robert Brown in the 1800s using a simple microscope. It was not until the end of the 1800s that Abbe first used a compound microscope in the way that we see them now, which is an arrangement of a couple of lenses, and you see an even further magnified image. So initially even the cell was discovered using a simple bead microscope, which I'll demonstrate to you later.

So this is how an image is formed in a simple microscope. It's very simple. You get to see a virtual, enlarged image, as you can see in this diagram. In a compound microscope, as I was saying, you have an arrangement of two lenses along the same line, and you get to see the magnification of both of them and so you get an even further magnified image. But as you can imagine, you have to make sure that the alignment and all these things of the lenses are in place.

So automatically the engineering effort to make a compound microscope is more, and which is why those are more expensive. They have to be fabricated in a facility, and they're usually kept under lock and key in your school. Whereas a simple microscope is something that you can make with a single bead and even carry it in your pocket and use it for studying various things. The magnification that you get from a simple microscope, if you just do the ray diagram, you'll find it's very simple. It's just 1 plus d, which is the least distance of distinct vision for our eye, so that's usually taken to be about 25 or 30 centimeters, divided by the focal length of the lens.

So that's how the magnification of a simple microscope, immediately tells you, that the smaller the focal length of the lens, which means the more curved it is, the larger the magnification. In the case of a compound microscope, of course, it,'s a product of the magnification of both the lenses, so you can get a much larger magnification using a couple of lenses which each have some certain magnification. But there are other issues with manufacturing something like that, which is why it needs to be done in a fabrication facility, whereas a simple microscope can be made, as we'll show you, just with your hands, if you just have the glass bead of the correct size. The other important thing to worry about in a microscope is how distinctly it can actually see the things behind in the specimen, and that's something that we call resolution, and that again depends on the aperture of the lens. So there the larger the aperture, the larger the size of the lens, and the greater the resolution.

But as we said, the larger the size, the smaller the magnification. So there's a balancing act that has to happen there. And also of course it depends on how far the object is kept from the lens, as well as the refractive index of the material of the lens. So these couple of things determine the resolution of, the maximum resolution of a microscope, and it of course is limited also by the wavelength of light. So that wavelength you're acting in, in our case visible light, determines the resolution of a lens.

So just to talk a little bit about the two types of microscopes, so simple microscope, as I said, it's easier to make, because it's a single lens that you can mount on anything and view through it. However, because it's so small, the focal length and everything is small, so you have to keep the bead very close to the sample, close to your eye. So slightly inconvenient and tedious to use. Anything that has a spherical surface, you get two kinds of aberration that happen. Of course yo,u get the distortion, which I'll show you in a picture, but you also get what's called aberration, because of the difference in the focal point, depending on where the ray is passing through the lens, it focuses at different distances.

So that's something called spherical aberration, and you have what's called chromatic aberration. Each of these lenses also disperses light a little bit, like a prism, right? So different wavelengths also focus at different distances, so you call that chromatic aberration. So that's of course a problem with any lens, and there are of course various ways to correct it. You put another lens, or you put another what's called an achromat, and you correct for those aberrations. But when you're making a simple microscope with just a simple one or one bead, you will get a little bit of these aberration effects.

Those aberration effects are also magnified further when you're using a compound microscope. So those aberrations happen more in a compound microscope, and there are ways to correct them. Simple microscope, there's less of it, but it's slightly more inconvenient to use, because you have to keep everything very close to your eye, and there's no distance that you have to play with. So things like focusing and all that are slightly harder. And of course that makes a simple microscope cheaper to make, and more valid for children to make in a classroom setting each one has.

Whereas a compound microscope may be something that you do use in higher classes, it's more expensive, more fragile, and stuff like that. One of the common optical issues that you have with a bead microscope that's so small is that you get to see distortion, because of the difference in the radius of the lens. Once you see through it, you get to see this kind of distorted line, and that's called your typical pin cushion distortion. You also have something called barrel distortion, where the sides seem to be bulging out. And there are various ways to correct it, based on where you can place the slit on the glass bead, and you can correct for these distortions.

Or if you look right through the middle, the middle part of the image is usually not distorted. I also spoke a little bit about spherical aberration and chromatic aberration just a while before, how it's a difference in the focal points of the various parts of the lens that causes different focal lengths, and so you get the spherical aberration, and how light disperses as it goes through a lens, with each wavelength focusing at a different point again on that principal axis, which causes a little bit of chromatic, meaning the color, aberration. So those are two aberrations that you have to worry about when you're looking at circular lenses. So given all this for a classroom setting, as I said, the bead microscope became kind of the best choice that we used to make a microscope. You can make it yourself, it's affordable, it was inspired by Professor Manu Prakash, who's a professor at Stanford University, who's been talking about using a bead and having that as your microscope, any child can use it, and he created this product called Foldscope, the idea being that you create a microscope which costs less than a dollar, which every child can have.

Our design for our microscope was inspired by the Foldscope. We'd borrowed, in fact, from Professor Sravanti here at APU, we'd borrowed Foldscope, it uses cardboard and a glass bead and is a complicated kind of thing, especially to get the focus and so on. So we went through a lot of steps in creating the design for the microscope. We started, of course, with the glass bead, but how do we mount it? We found the cardboard a bit flimsy and hard to focus on, then we tried to mount it on a hard piece of cardboard, a thick cardboard.

That also became flimsy after some time. Eventually, we settled on an ice cream stick. So you make a small hole in the ice cream stick, mount the bead in there, and then that stays quite nicely. You put some tape and foam to secure the bead to the ice cream stick, and that became the DIY microscope that we made. You can use beads of a couple of sizes. As I said, the smaller the bead, the larger the magnification.

So we sometimes have mounted a 4.5mm bead and a 2.5mm bead on the ice cream stick, and depending on what we want to see and how much detail we want to see, you can use either bead to observe your samples. We have some 10 or 15 activities that ThinkTac has curated and created, which use the bead microscope. It could be to observe plasmolysis, to look at onion cells, to look at cheek cells, fungi, mold, leaf venations, stomata, various things, and biological samples that we found useful with the lens. What's also incredible is you can put that lens on your phone screen or a TV screen and see the RGB grid, measure the pixel size, and understand what resolution is when we are talking about all these 720x1080 and all these numbers that you hear about the resolution of a screen, all those you can physically look at by putting just this bead microscope on one of these screens and observing the RGB grid and so on.

This makes it a very versatile tool for studying various bio as well as some physics concepts So this is what I'll show you now how simple this bead microscope is and how we can see various objects from it. So as you can see, the design is extremely simple of this bead microscope, how we've done it. We mount this glass bead, as you can see here, on the ice cream stick itself. So you just make a small hole with a pair of scissors and you can mount that bead depending on the size of the ice cream stick.

We put some foam and tape to keep it in place and at the back we even stuck a grid, a 1mm by 1mm grid, so that you can tell what the size of the specimens are. This is a simple slide that's been made with an onion peel, and stained with saffron. And again, because the bead is small, focal lengths are small, etc., the sample pretty much has to be touching the bead. And then when I look through this, I get to see the onion peels.

Now you can't see it, so we've built another small device which helps you to be able to see the cells. So this is a clip that I can stick on my mobile phone, for example. So here I have again the same glass bead, about 3 or 3.5mm in diameter, that's mounted on this clip. And we've made it such that we can just insert this slide onto the clip here.

And I can place this on my mobile phone right here on the camera. Once I turn on the phone and turn on the camera, I'm able to see this, the onion cells. So you can even actually, if you look closely, you're able to also see the nucleus of some of the cells and so on. So an extremely beautiful kind of image that you get. And there's a huge amount of wow when you see something like this directly with your own eyes, with something that you've built yourself. So as you can see, we've tried various designs. This one was directly mounted on an ice cream stick. Here we've put it on a plastic clip. Here we've mounted the bead on a rubber grommet. And that allows me to again place it here quite easily. And I can put it on my laptop screen, for example.

So I'll just get my laptop here. And by placing it here, you can even see the pixel grid. You can see the RGB grid and distinctly also easily see the size of the grid, which lights are on when it's white. You can change the color of the screen and see you get different bulbs glowing in that RGB grid. So you also understand what it means to be a red, green, and blue grid, and how those primary colors are used to get all the colors that we see on a computer screen. Or even our eyes have three color receptors, the same primary colors.

And so you can explore all that and understand it even more when you see it through this bead microscope. Now that you've seen this activity of what I just showed you with the ready-made microscope, this video here shows you how it's made. And just using the glass bead and how it's mounted on an ice cream stick. Once you've made the microscope, of course, you can use it for, as I said, various experiments. In this particular video, I'm showing you how you can observe it to look at plasmolized cells.

So here we dip an onion peel inside a saltwater solution and the cells shrink. And then we have a normal onion peel where we've not done the plasmolysis. And you can see the difference in the size of the cells with this particular microscope. So that's what this particular experiment shows you. So as you saw, the size of the cells varies. And how do we know that? It's very simple. Behind the bead, we stick a small grid, either a 1mm by 1mm or a 1.5mm by 1.5mm grid. So you can see the grid lines superimposed on the cells.

So you can measure the size of the cells as well. And, you can do that with the grid as I was telling you earlier. And you can figure out lots of things about various samples just through this simple microscope. We have found that this bead microscope creates a huge amount of excitement and buzz among teachers and students alike. Almost in all settings, whether we've tried it with government school teachers in far-flung areas of India, or with so-called premium elite schools, we find that the wow that comes, and that's what we want when children build something and get excited about it, we find that with the microscope it's almost universal. In fact, in the school where I used to study, the Valley School, the physics teacher there happened to get very excited about it and took it for a project that he was doing with school kids in Himachal Pradesh.

While doing that, one of the students at the Valley School at the time got inspired by using the bead and was quite excited by it then happened to come to APU to study physics. He just graduated a couple of days ago, and the senior thesis project that he used was again using these glass beads. He made what's called a wavefront sensor, Shaq Hartman Wavefront Sensor, that's used heavily in astronomy in adaptive optics instruments. The idea is that you can measure the form of a wave based on having these various lenses. So each lens will focus the incoming wave of light at slightly different points.

So if you have a grid of these lenses, you can tell what the shape of the incoming wave was. Is it deformed, is it a spherical wavefront plane wavefront on, and so forth? So he used these beads to make a very simple and, but still, effective version of a wavefront sensor. He made a pretty complicated optical instrument with, again, these very simple beads, and so therefore possible to do at a low cost, and got good results for his thesis project by making this wavefront sensor. So we've had lots of stories like this, where children use something like this in school, they see the microscope or the bead microscope for the first time, and they're getting inspired by it and using it to do more and more research as they go into college, maybe use it later in their life as well to make something even more complex.

So there's a lot of scope that happens when children use anything hands-on at a young age to understand concepts. It stays with their mind, it inspires them, teachers get excited, and the classroom is more enjoyable. So we encourage a lot of making and experimentation to happen in the classroom itself. We also, as I said earlier, collaborate with a lot of institutes, and APUs, one of them, and another one of our friends is in IIT Gandhinagar at the Center for Creative Learning. So they've used our bead microscope and done a lot of observations with it.

They've looked at things like the mosquito head, they've looked at cells, and so this video here, which will briefly show you how they've used the microscope, and they've even taken the lens out of a laser light and mounted it on the phone, and you can use that also as your microscope. You can see things like the head of a bee, or you can see details of a head or insect or fibers, all these wonderful things just using the simple idea of a bead microscope. As you can see, it's a very versatile tool, useful to see a whole host of biological samples. There's a long history, of course, of how the microscope has been used through human history, especially in the last 400, and 500and years, and how a lot of those biological discoveries happened with the simple bead microscope. So even though we use compound microscopes nowadays in the lab or to do high-end research, it all started with a simple bead.

Sometimes you might notice even a drop of water on your phone is kind of, you can see the grid behind it. It's the same concept. Maybe that's what inspired the first person to, you know, use a piece of glass and observe things on a small scale. Of course, we've come a long way since then, but we encourage children to continue using a simple bead microscope in the classroom and observe various things that are there around them in their daily lives and hopefully get inspired to do something further in their higher studies or just simply have the microscope in your pocket and, you know, look at the world around you in a very microscopic way. I hope you enjoyed this short introduction to bead microscopy and enjoyed the presentation. Thank you.